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**Work Plan for an
Engineering Evaluation/Cost Analysis
in Support of the Risk-Based Approach
to Remediation at Site ST14**



**Carswell Air Force Base
Fort Worth, Texas**

Prepared For

**Air Force Center for Environmental Excellence
Brooks Air Force Base
San Antonio, Texas**

and

**Carswell Air Force Base
Fort Worth, Texas**

June 1994

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SECTION 1

INTRODUCTION

This work plan was prepared by Engineering-Science, Inc. (ES) and describes the scope of work required for the collection and analysis of data to complete an engineering evaluation/cost analysis (EE/CA) in support of a risk-based remediation decision for soil and ground water contaminated with JP-4 fuel hydrocarbons at Site ST14 at Carswell Air Force Base (AFB), Fort Worth, Texas. Site ST14 consists of two separate sites: Site ST14A, the Fuel Loading Area, and Site ST14B, the petroleum, oil, and lubricant (POL) tank farm. This work plan is the equivalent of a treatability study test design (TSTD) for the field test of the risk-based approach for the remediation of Site ST14. This innovative technology demonstration is sponsored by the Air Force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas, under contract F41624-93-C-8044, "Risk-Based Approach to Fuel Spill Remediation." The Site ST14 demonstration is a component of a multi-site initiative being sponsored by AFCEE to demonstrate how quantitative fate and transport calculations and risk information based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at a site to minimize contaminant migration and receptor risks.

1.1 GOALS AND OBJECTIVES

The risk-based approach is designed to combine natural, or intrinsic, remediation with low-cost source removal technologies such as *in situ* bioventing to economically reduce the risk of subsurface petroleum spills. There are three primary goals of this demonstration project at Site ST14. The first goal is to determine if remedial actions are necessary to minimize contaminant migration and potential receptor exposure to fuel-hydrocarbon-contaminated environmental media at Site ST14. The second goal is to implement any necessary and appropriate remedial technologies at Site ST14. It is possible that at some fuel-contaminated sites, intrinsic remediation alone will be sufficient to minimize or eliminate potential risks to human health and the environment. Implementation of the intrinsic remediation option under these circumstances would require only long-term monitoring to confirm the effectiveness of this remediation approach. At other sites, however, it may be necessary to supplement intrinsic remediation and long-term monitoring with some type of engineered solution, such as source removal, to minimize contaminant migration and receptor exposure. A combination of removal (e.g., free product recovery, bioventing), decontamination (e.g., intrinsic remediation), and/or control technologies (e.g., long-term monitoring, land use restrictions) constitute a remedial alternative (TRNCC, 1993). The third goal

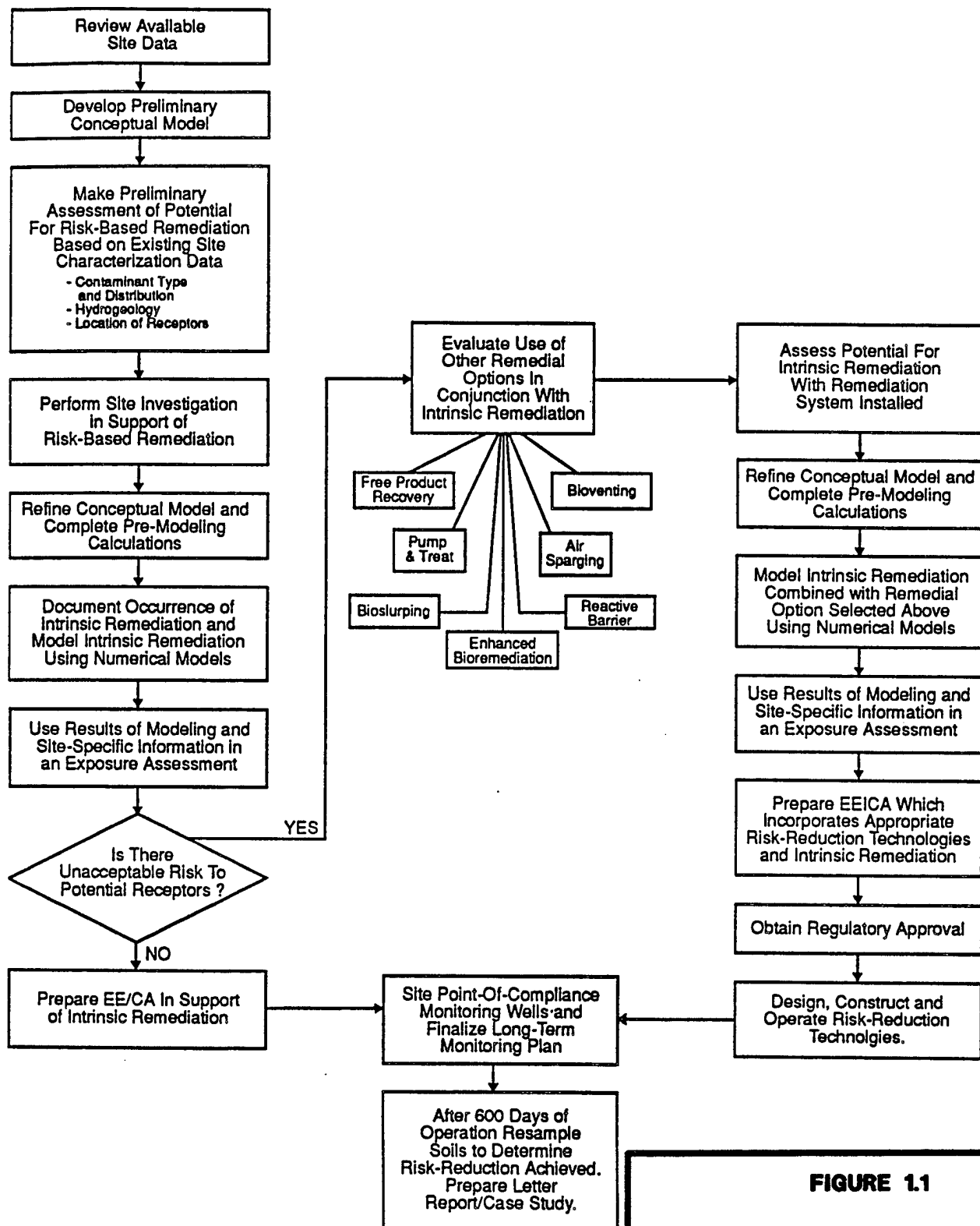


FIGURE 1.1

RISK-BASED REMEDIATION FLOW CHART

TSTD/Work Plan
Risk-Based Approach to Remediation
Site ST14, Carswell AFB, Texas

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is to collect data on how best to implement a risk-based remediation at a site, which will eventually be incorporated into a programmatic protocol on the Risk Based Approach (RBA). This protocol document will standardize site characterization, modeling, and interpretive procedures. Lessons learned and case studies developed as part of this demonstration program will be factored into the protocol document to illustrate how best to complete a risk-based remediation of a site.

The specific objective of the work described herein is to develop an EE/CA that identifies and evaluates an appropriate remedial alternative for contaminated environmental media at Site ST14 at Carswell AFB, Texas, that will be protective of human health and the environment. This TSTD/work plan is intended to meet the technical, procedural, and documentation requirements of Risk Reduction Standard No. 3 as defined by the Texas Natural Resource Conservation Commission (TNRCC) in Sections 335.551 - 335.569, Subchapter S, of Chapter 335 Industrial Solid and Municipal Hazardous Waste Management. Risk Reduction Standard No. 3 has been defined as "closure/remediation with controls to remove, decontaminate, and/or control all waste, waste residues, leachate, and contaminated media to levels and in a manner such that any substantial present or future threat to human health or the environment is eliminated or reduced to the maximum extent practicable," as specified in Section 335.561 concerning attainment of Risk Reduction Standard No. 3. The EE/CA will be prepared to satisfy the documentation requirements of Risk Reduction Standard No. 3. This TSTD/work plan describes the specific site characterization activities and data analyses which will be performed in support of the EE/CA and the risk-based approach to remediation for Site ST14.

1.2 SCOPE OF WORK

The major milestones of this demonstration project are as follows: (1) gather site-specific data on the nature and extent of contamination in the soil, ground water, and surface water at Site ST14; (2) determine whether an unacceptable risk to human health or the environment currently exists or may occur in the foreseeable future using quantitative contaminant transport models and risk estimates; and (3) evaluate, recommend, design, construct, and operate an innovative remedial alternative that both reduces the source of contamination and minimizes or eliminates potential risks to human health and the environment due to exposure to Site ST14 contamination. These major milestones are briefly described in this section and illustrated in Figure 1.1.

1.2.1 Determining Contaminant Distribution

The risk-based approach for the remediation of Site ST14 parallels the TNRCC's risk reduction rules which require remediation activities to provide risk reduction to levels that are protective of human health and the environment through the use of a remedial alternative that is permanent or has a high degree of long-term effectiveness (TNRCC, 1993). These rules require specific information and reports which are commensurate with the type of risk reduction standard to be demonstrated, the degree of risk posed by the contaminated area, and the type of remedial action to be performed. The TNRCC's risk reduction rules allow for integrating site-specific data into standardized risk assessment procedures to develop and determine final site-specific cleanup levels. It is the intent of the Air Force to demonstrate a risk-based

remediation of Site ST14 pursuant to Risk Reduction Standard No. 3, as defined by TNRCC's risk reduction rules. Therefore, site characterization efforts required to demonstrate attainment will involve identifying the principal risks at the site which must be addressed by a combination of source removal, intrinsic remediation, and long-term monitoring.

Site characterization studies in support of the risk-based approach for the remediation of Site ST14 will consider the four primary contaminant phases associated with subsurface JP-4 fuel hydrocarbon contamination: vapors in the soil gas of the vadose zone soils, residual fuel in the vadose zone (unsaturated) soils, free-phase product floating on the ground water, and dissolved-phase fuel contaminants in the ground water. Volatilization and upward molecular diffusion of fuel hydrocarbon contamination can result in measurable concentrations of hydrocarbons in the vadose zone soil gas and above-grade atmosphere. If present in sufficient quantities, fuel will spread downward and laterally through the vadose zone soils, leaving residual fuel in the vadose zone which can create a long-term ground water contaminant source (Abdul, 1987; American Petroleum Institute, 1980). Gradual partitioning of fuel contaminants from either the free-phase source or the residual fuel product in vadose zone soil into ground water results in a dissolved-phase contaminant plume that can migrate downgradient under the influence of mass transport processes (e.g., Domenico and Schwartz, 1990). If contaminated ground water discharges to a surface water body, dissolved-phase hydrocarbons may also contaminate the surface water. Site characterization activities for Site ST14 will include sampling of soil, soil gas, surface water, and ground water. Sufficient samples will be collected and analyzed to assess the risk to human health and the environment and to demonstrate attainment of site-specific risk-based cleanup levels. Section 4 of this TSTD/work plan provides additional details on site characterization data needed to support a risk-based approach to remediation at Site ST14.

1.2.2 Estimating Potential Risks to Human Health and the Environment

The risk-based approach to remediation is dependent on conservatively estimating levels of residual fuel that can remain onsite and not pose an unacceptable risk to human health or the environment. Risk Reduction Standard No. 3 allows site-specific flexibility in determining which potential remedial alternatives afford the highest degree of long-term effectiveness appropriate for the current and future uses of the site. Both the US Environmental Protection Agency (EPA) and TNRCC recognize that the mere presence of a contaminant does not necessarily warrant remediation, and that the goal of remediation investigations is to determine what remedial actions are necessary to eliminate or minimize risks to human health and the environment (EPA, 1987; TNRCC, 1991). Using site-specific data, a quantitative source-and-release analysis and an exposure pathway analysis will be completed to determine which if any of the four contaminant phases (i.e., soil gas, contaminated vadose zone soils, free-phase product, and dissolved-phase contamination) may pose a risk to human health and the environment. Quantitative contaminant fate and transport models such as Bioplume II (Rifai et al., 1988) will be used to determine whether fuel contaminants could migrate to a potential receptor exposure point. This is one of the key steps in the risk-based approach to remediation because it ensures that costly engineered solutions are not

employed at a site which does not and will not pose a risk to human health and the environment.

However, in the event that site data indicate that contamination from Site ST14 could migrate to a potential receptor exposure point, site-specific, risk-based cleanup goals will be developed using well-defined quantitative procedures to determine the cleanup levels necessary for each medium to eliminate or minimize current and potential future risks to human and ecological receptors. These quantitative risk-based cleanup goals will be used to assess whether it will be necessary to supplement intrinsic remediation with an engineered remediation technology to minimize or eliminate potential risks.

The risk-based approach to remediation is not intended to replace a traditional baseline risk assessment where the final decision is whether remedial actions are necessary at a site (EPA, 1989b; TRNCC, 1993). However, a baseline risk assessment will not be necessary at sites to be addressed using the risk-based approach as it has already been determined that some action will be taken. The risk-based approach is more analogous to an evaluation of the long-term risks associated with implementing a specific remedial action at a site (EPA, 1991b). This innovative approach streamlines the remedial decision process by focusing data collection and evaluation on identifying which remedial action most cost-effectively reduces potential risks to human health and the environment. The risk-based approach compresses the traditional multi-step remediation process into one project with the intent of quickly and cost effectively reducing risks associated with chemical contamination at or migrating from Site ST14.

A quantitative, iterative process will be used to assess the potential effectiveness of various remedial alternatives (e.g., intrinsic remediation alone vs. various source removal options coupled with intrinsic remediation) in minimizing contaminant migration and receptor exposure. Chemical-specific, risk-based cleanup levels will be derived using site-specific data and quantitative human health-based risk assessment procedures whenever a chemical-specific standard or alternate concentration is not available or appropriate (TNRCC, 1993). These risk-based cleanup levels will incorporate data on technical limitations, effectiveness, practicability, and other relevant features of the various remedial alternatives considered appropriate for the site. The final cleanup levels will be factored into the final design of an appropriate remedial action for Site ST14. Sections 2 and 5 of this TSTD/work plan provide more detail on how human health and environmental risks associated with various remedial alternatives considered for Site ST14 will be evaluated as part of this demonstration.

1.2.3 Developing an Appropriate Remedial Approach

The risk-based approach for the remediation of Site ST14 is intended to quickly define a remedial alternative that will reduce or eliminate significant risks to human health and/or the environment. Identification and evaluation of any remedial technology, including intrinsic remediation, will be based on an evaluation of (1) long-term effectiveness; (2) permanence; (3) ability to reduce contaminant toxicity, mobility, or volume; (4) implementability; and (5) cost, per the requirements of Risk Reduction Standard No. 3 (TNRCC, 1993). The EE/CA must provide sufficient technical data on the recommended remedial alternative to show that it eliminates or

abates present and future threats to human health and the environment to the maximum extent possible, and that appropriate control measures such as long-term monitoring are designed to supplement intrinsic remediation or any engineering controls.

A key objective of this evaluation will be to determine potential short- and long-term risks to the community and site workers. Determining how effective any one remedial technology may be at achieving desired protective remediation levels will require application of data from past treatability studies, an understanding of governing contaminant fate and transport processes, and engineering judgment. Both quantitative and qualitative analyses will be completed in support of the selection and design of an appropriate remedial action for the site. Long-term monitoring as part of this demonstration project will likely involve the installation and sampling of sentry and point-of-compliance wells. Sentry wells will be located immediately downgradient of the existing plume and will provide for early confirmation of model and engineering predictions. The point-of-compliance wells will be located further downgradient to verify that site-related contamination does not pose an unacceptable risk to potential receptors over time. Any requirements for institutional controls or long-term monitoring required to protect human health and the environment will be clearly described in the EE/CA (TNRCC, 1993). Requirements for long-term monitoring will be dependent upon the permanence or degree of long-term effectiveness afforded by the recommended remedial alternative.

Evaluation of remedial technologies as part of this demonstration project will also focus on whether the technology can readily and economically achieve desired remediation levels and what uncertainties may be involved in this determination. Details on implementability with respect to expected time to achieve desired remediation levels and any short-term engineering controls or mitigation measures will be factored into the evaluation. Identifying and assessing specific remedial technologies will also provide valuable information as to which technologies will clearly not reduce significant risks to human health or the environment.

The risk-based approach to remediation should streamline the remedial decision-making process by providing sufficient data to support the selection, design, and implementation of a low-cost final remedial alternative for Site ST14 that will minimize contaminant migration and potential receptor exposure. The streamlined process should also reduce the amount of time between identification of a potential risk to human health and the environment and remediation of that risk. Additionally, site data to be collected will assist in subsequent risk analysis and remedial design efforts for other contaminated areas at Carswell AFB by quantifying source release and transport mechanisms in local soils and estimating remedial technology efficiencies.

1.3 TSTD/WORK PLAN ORGANIZATION

This TSTD/work plan is oriented toward the collection of site-specific data to be used to complete quantitative analyses of contaminant migration potential and the potential risks associated with contaminant migration. This TSTD/work plan describes the need for additional data and how that data will be collected in the field and then analyzed using contaminant fate and transport models such as Bioplume II. Data from completed and ongoing treatability studies, such as the bioventing pilot test, will be

used both to characterize the current nature and extent of potential source contamination and to estimate the effectiveness of additional source removal activities at Site ST14, should such measures be necessary to minimize future contaminant migration and receptor exposure. This TSTD/work plan also describes the methods of risk analysis that will be used to identify and develop remedial actions for Site ST14. This TSTD/work plan was prepared to coordinate the activities of all agencies involved in the EE/CA, including ES, AFCEE, and Carswell AFB.

This TSTD/work plan is based on a review of existing site characterization data and the data needs of the risk-based approach to remediation. The TSTD/work plan consists of seven sections, including this introduction. Section 2 summarizes existing data on the physical characteristics and nature and extent of contamination at Site ST14. Section 3 presents a conceptual site model that will aid in defining necessary site characterization activities and subsequent data analyses. Section 4 describes the data needs of the risk-based approach to remediation for Site ST14. The proposed sampling strategy for the collection of additional site characterization data is presented. Section 5 discusses the proposed risk analysis methods and the EE/CA report format. Section 6 includes a proposed schedule defining milestone dates for the demonstration project at Site ST14. Section 7 contains the references used in preparing this document. This TSTD/work plan also contains two appendices. The first appendix is the detailed, site-specific field sampling and analysis plan. The second appendix is the site-specific addendum to the programmatic health and safety (H&S) plan.

SECTION 2

REVIEW OF AVAILABLE SITE DATA

Existing site-specific data were used to describe the physical characteristics of environmental media and the nature and extent of contamination at Site ST14. Review of available site data will aid in defining the additional site characterization data necessary to fill current data gaps, support quantitative modeling efforts, develop long-term risk-based cleanup levels, and evaluate, select, and implement the most cost-effective remedial alternative for the site.

2.1 SITE BACKGROUND

Carswell AFB is located approximately 6 miles west of the center of Fort Worth, Texas (Figure 2.1). ST14 is located in the eastern portion of the base near the Carswell AFB main gate. The site consists of two separate areas: Site ST14A, the Fuel Loading Area located on the east side of Knights Lake Road, and Site ST14B, the POL tank farm located on the west side of Knights Lake Road. Site ST14B is characterized by two above-ground fuel storage tanks. Three additional tanks formerly located at Site ST14B have since been dismantled. Site ST14 consists of the fuel loading area along the eastern side of the road, and the area southeast and downgradient of the fuel loading area to the southern boundary of Carswell AFB. Figure 2.2 shows the location of Sites ST14A and ST14B on Carswell AFB.

During the early 1960s, JP-4 fuel was discovered in soil and ground water at and downgradient of Site ST14. Leaking underground fuel lines are the suspected source of subsurface contamination at this site. A french drain system was installed downgradient of the site in 1965 to collect fuel hydrocarbon products leaking from Site ST14. The french drain system is connected to an underground oil/water separator (Facility 38) located south of the new communications building (Building 1337) and immediately south of the fenced civil engineering storage yard. Based on information gathered as part of the 1990 Installation Restoration Program (IRP) sampling event, the french drain system continues to collect fuel product (Radian, 1991). Treated water from this oil/water separator becomes the perennial Unnamed Stream, which flows into Farmers Branch, which in turn discharges to the Trinity River along the eastern boundary of Carswell AFB.

Site ST14 has been characterized under the US Air Force IRP (Radian, 1986, 1988, 1989, 1990, and 1991), and as part of the bioventing pilot test program sponsored by AFCEE (ES, 1993). Additional site investigation work, performed by Law Environmental Government Services in March of 1994 (in progress), has further defined the extent of subsurface JP-4 fuel hydrocarbon contamination. The results of

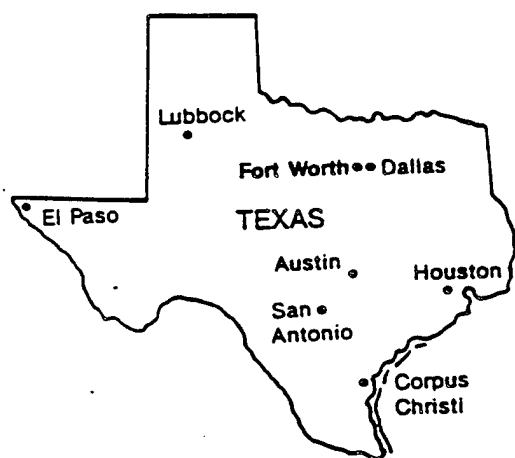
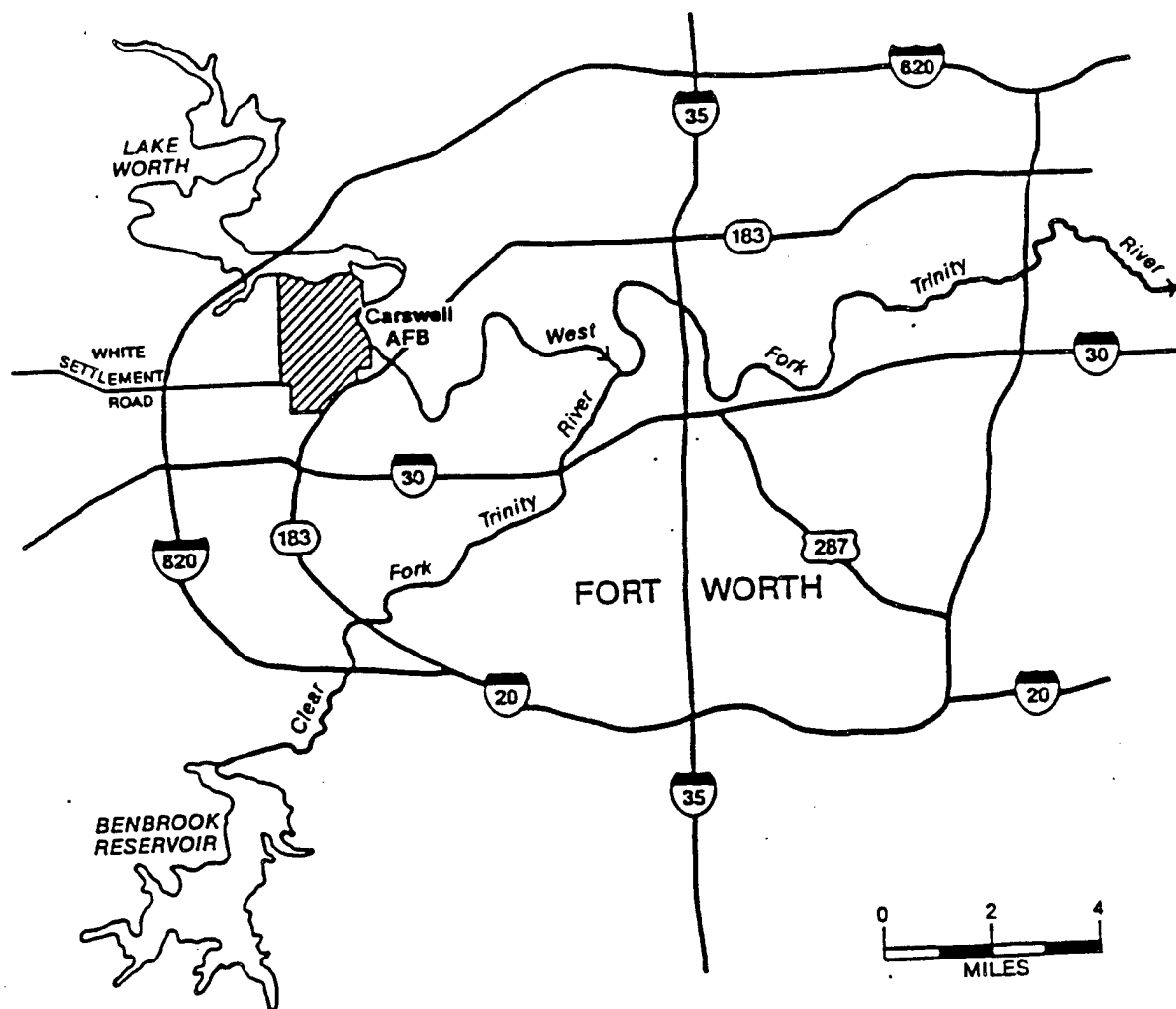


FIGURE 2.1

**REGIONAL LOCATION OF
CARSWELL AFB**

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Risk-Based Approach to Remediation
Site ST14, Carswell AFB, Texas

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these investigations indicate soil and ground water fuel hydrocarbon contamination, including a thin free product film, in the vicinity of ground water monitoring well ST14-17M, which is located in the center of Site ST14A, and ground water monitoring well ST14-17J, which is located between Tanks 1156 and 1157 on Site ST14B (see Figure 2.2).

Benzene, ethylbenzene, chlorobenzene, toluene, and total xylenes have been detected in the ground water at Site ST14. Of these contaminants, ethylbenzene was detected most frequently. However, benzene was the only volatile organic compound (VOC) detected at a concentration above its federal maximum contaminant level (MCL) of 5 micrograms per liter ($\mu\text{g/L}$). The benzene concentration that exceeded the MCL was 16 $\mu\text{g/L}$, detected in a sample from well ST14-17M (Radian, 1991). The highest concentrations of chlorobenzene, toluene, and total xylenes also were recorded at this well location.

More than 2 feet of free product was encountered in 1990 at well ST14-17M during ground water sampling. However, hand bailing of this well by base personnel during 1993 and recent preliminary investigations completed in 1994 by ES indicate that little recoverable product remains in this area. Further details on the physical characteristics of Site ST14 and the probable nature and extent of subsurface fuel hydrocarbon contamination are presented in subsequent sections of this TSTD/work plan.

2.2 PHYSICAL SETTING

Data from previous site characterization efforts were reviewed, and relevant portions of these data are summarized in the following sections.

2.2.1 Site Topography and Surface Hydrology

The East Area of Carswell AFB includes several discrete sites that may be potential sources of contamination. Figure 2.3 shows the location of the East Area with respect to the entire Carswell AFB and the surrounding environs. The East Area has relatively flat topography which slopes gently eastward and southward. No abrupt elevation changes occur within the East Area except close to the Trinity River.

The main surface water bodies located in the East Area are the West Fork of the Trinity River, Farmers Branch, the Unnamed Stream, and the Flightline Drainage Ditch (see Figure 2.2). The West Fork of the Trinity River is located approximately 1,600 feet east of Site ST14A, and Farmers Branch (a tributary of the West Fork of the Trinity River) is located approximately 1,000 feet southeast of Site ST14. Farmers Branch discharges into the Trinity River near the eastern base boundary. Estimates of flow in Farmers Branch made in April 1990 averaged 6 cubic feet per second (cfs) (Radian, 1991). However, the flow in Farmers Branch is highly variable and can range from less than 5 cfs to more than 100 cfs, usually after significant precipitation events. Based on initial site investigations, the ground water gradient at Site ST14 is toward the east-southeast, which suggests that shallow ground water may discharge into both Farmers Branch and the Trinity River. Comparison of water level measurements in ground water monitoring wells and staff gauge measurements from Farmers Branch also seem to suggest this stream is receiving ground water inflow from adjacent alluvial terrace deposits (Radian, 1991).

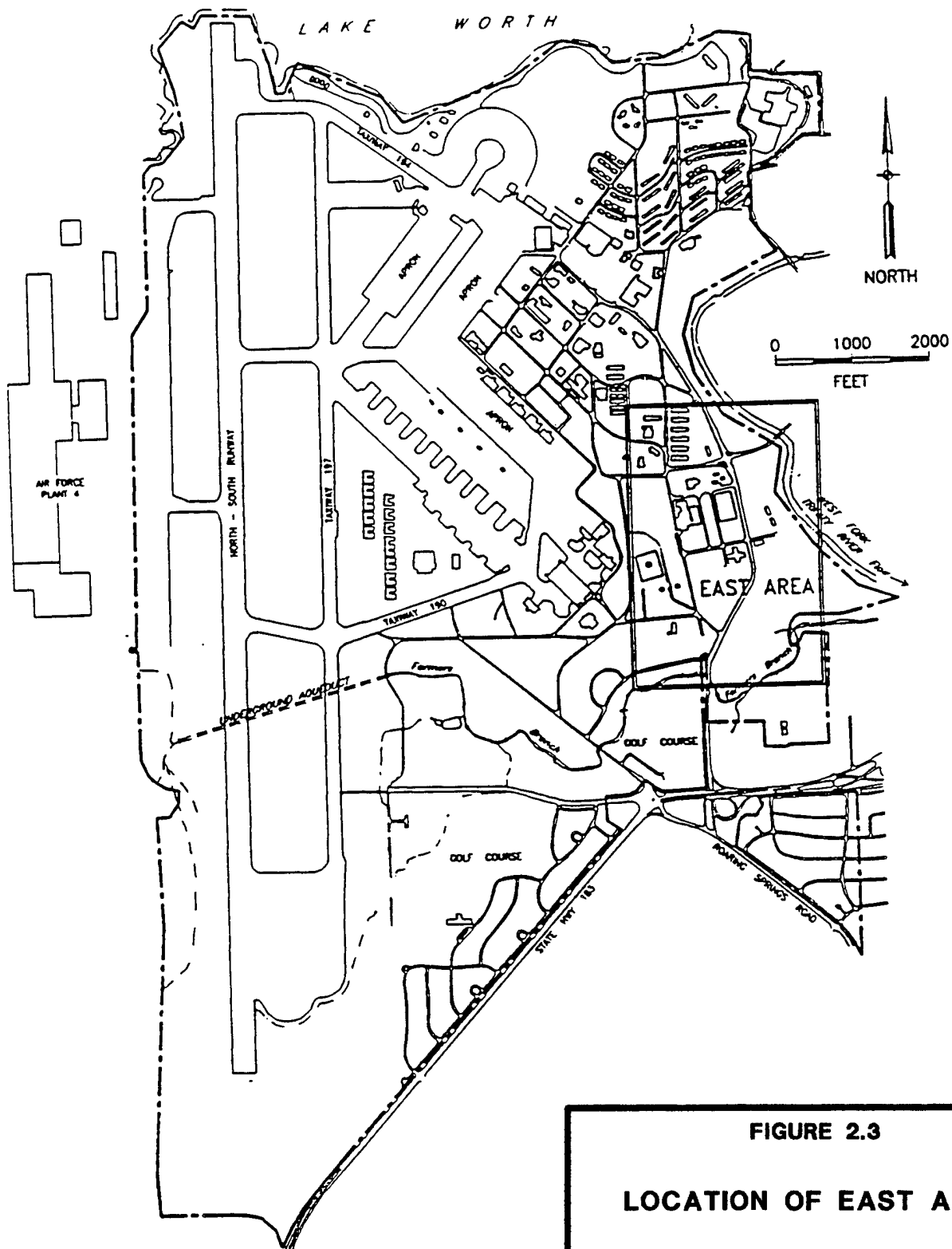


FIGURE 2.3

LOCATION OF EAST AREA

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Risk-Based Approach to Remediation
Site ST14, Carswell AFB, Texas

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In 1965, a french drain system was installed approximately 600 feet downgradient of the Fuel Loading Area to intercept free-phase fuel product leaking from Site ST14 or another site in the area to prevent it from advancing toward Farmers Branch and the Trinity River. Ground water collected by this french drain system is routed to an underground oil/water separator (Facility 38) located south of Building 1337 and immediately south of the fenced civil engineering storage yard (see Figure 2.2). The perennial Unnamed Stream emerges from this underground oil/water separator and flows into Farmers Branch at an average rate of 0.2 cfs. The primary source water for the perennial Unnamed Stream is apparently the french drain system, although natural ground water seepage may also be a water source (Radian, 1991).

Surface elevations range from 580 feet above mean sea level (MSL) west of Site ST14 to 560 feet MSL on the flood plain above the Trinity River. Surface drainage is primarily toward Farmers Branch, with some drainage into the concrete-lined portion of the Flightline Drainage Ditch (Site SD10). This major stormwater drain passes through the middle of Site ST14B and may have some effect upon ground water.

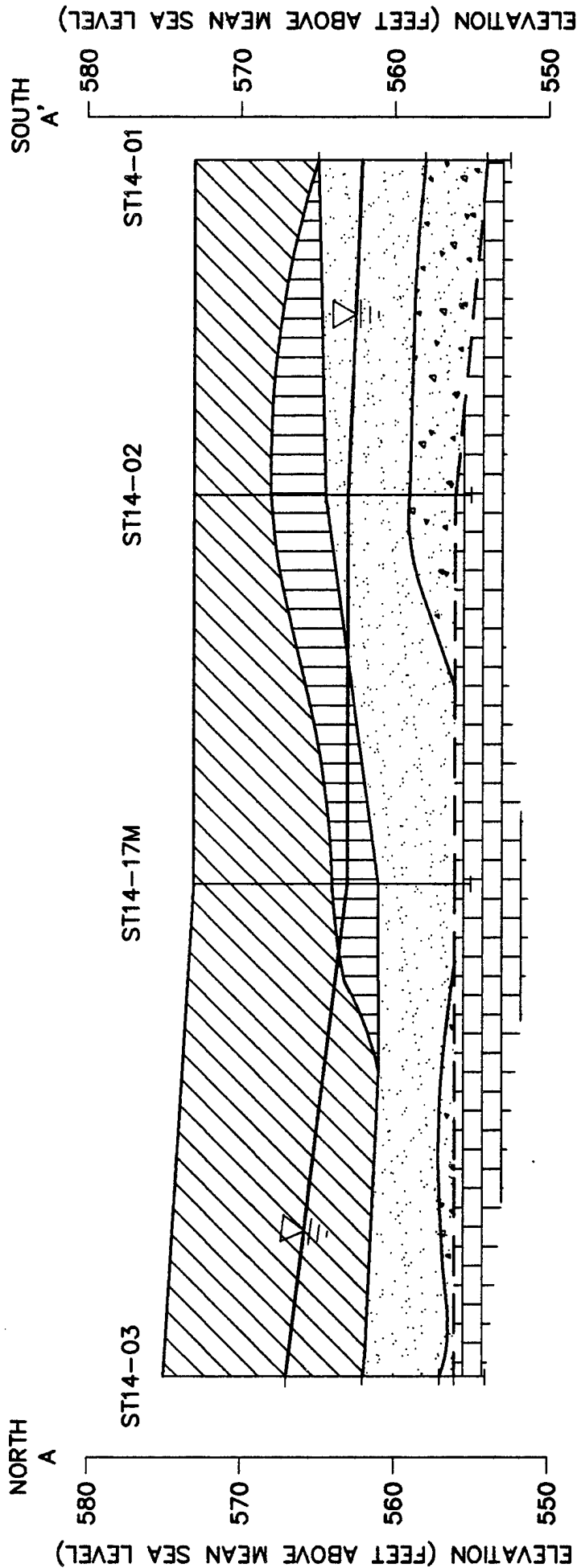
Surface features at the site include landscaped areas; concrete, asphalt and crushed rock driveways and parking areas; two above-ground Tanks 1156 and 1157; and several warehouse structures, including Buildings 1213 and 1214 which are immediately downgradient of the apparent source area within Site ST14A. Underground fuel pipes, which leaked previously, are the suspected source of contamination at Site ST14.

The Soils Conservation Service (SCS) has identified one primary soil association at Site ST14, clayey soils of the Sanger-Purves-Slidell association. The permeability of these surficial soils can range from less than 4.2×10^{-5} to 3×10^{-3} centimeters per second (cm/sec) (Radian, 1991).

2.2.2 Site Geology and Hydrogeology

The geology of the East Area consists of a thin veneer of alluvial material overlying the Goodland Limestone, Walnut, and Paluxy Formation. The alluvium, called the Upper Zone, consists of unconsolidated Quaternary and Recent alluvial deposits of sand, gravel, silt, and clay, and can extend to a depth of approximately 20 feet below ground surface (bgs). Generally, the stratigraphy of the Upper Zone can be described as 5 to 15 feet of gray to black clay overlying 2 to 10 feet of fine-grained sand and up to 5 feet of gravel. The underlying Goodland and Walnut Formations contain fresh and weathered limestone and shale. The Goodland Formation, the shallowest bedrock unit, is usually encountered from 7 to 20 feet bgs. In general, the depth to the Goodland Formation increases eastward toward the Trinity River. These geologic units form a basal confining unit to the Upper Zone, the shallowest water-bearing geologic unit. No borings have been completed as part of previous investigations at Site ST14 that penetrate through the Goodland/Walnut Formations to the underlying Paluxy Formation.

Figure 2.4 depicts the location of the hydrogeologic cross section developed under previous site investigation efforts used to characterize the stratigraphy of Site ST14. Figures 2.5 and 2.6 show the north-south and east-west hydrogeologic cross sections for Site ST14. At Site ST14, the upper 10 to 12 feet of unconsolidated alluvial deposits consist of highly plastic, olive-gray to black, sandy clay soil with some



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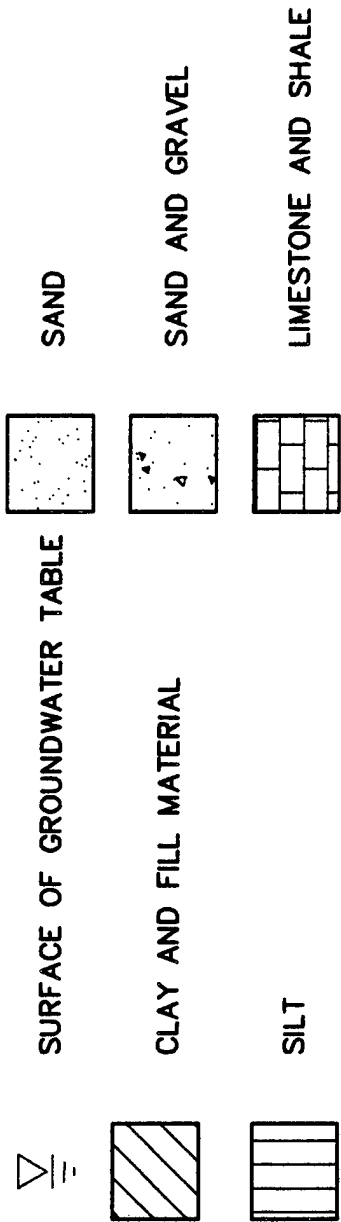


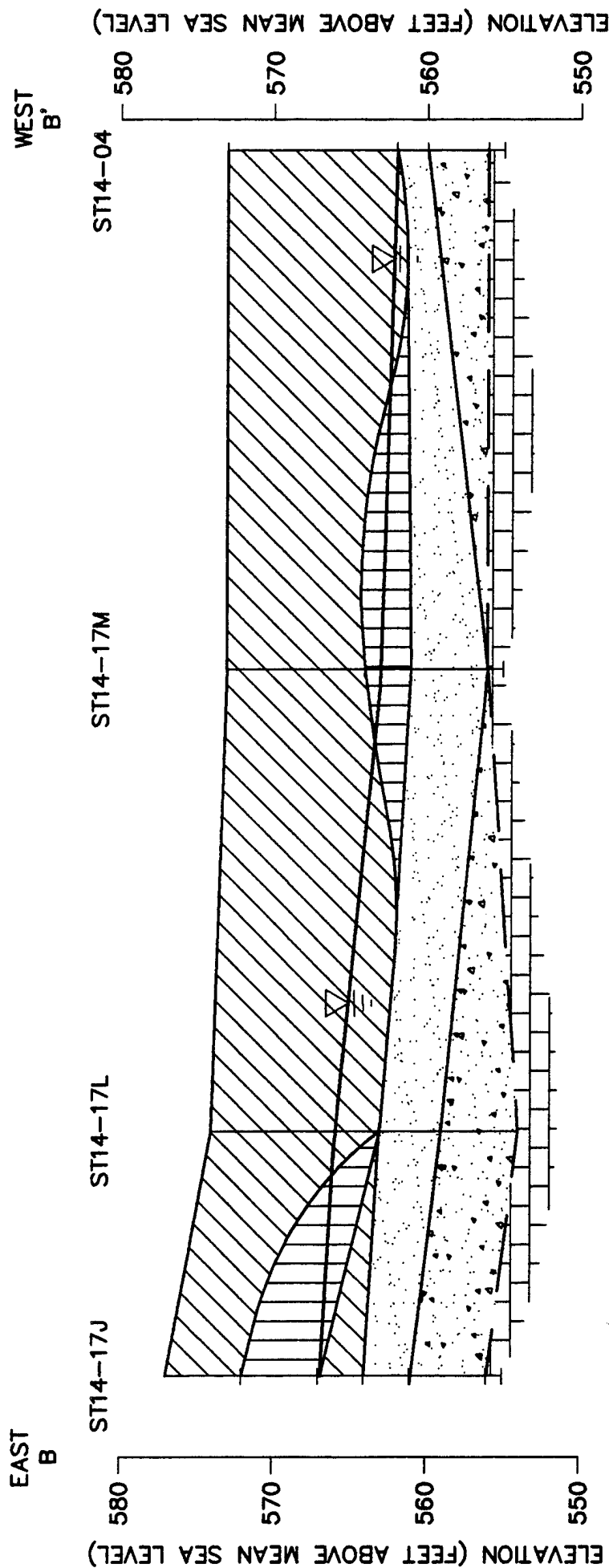
FIGURE 2.5

NORTH-SOUTH HYDROGEOLOGIC CROSS SECTION A-A'

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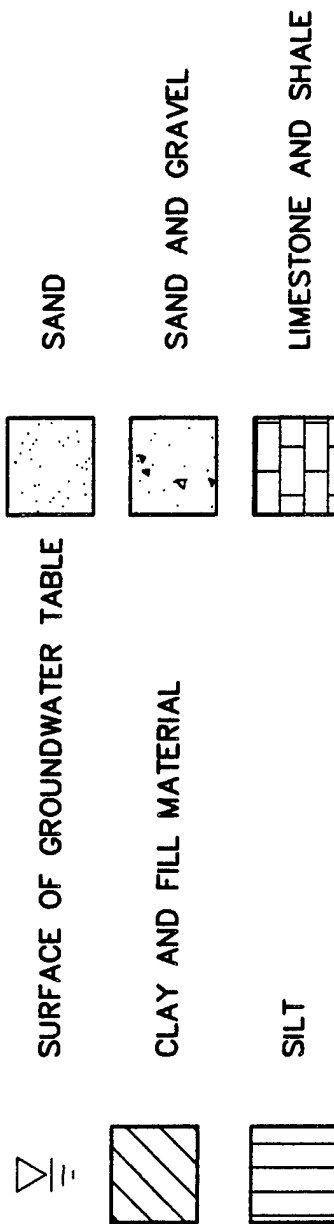


FIGURE 2.6

EAST-WEST HYDROGEOLOGIC CROSS SECTION B-B'

TSTD/Work Plan
Risk-Based Approach to Remediation
Site ST14, Carswell AFB, Texas

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interbedded gravel and silt, underlain by 5 to 10 feet of sand and gravel. Gravel content of these alluvial materials generally increases with depth. Gravel ranges from pea size to pebbles over 1 inch in diameter. The depth to the Goodland Formation bedrock surface at Site ST14 ranges from 16 to 20 feet bgs. Where the elevation of the Goodland limestone is known, it forms a fairly uniform, gently southward-dipping surface at approximately 555 feet to 556 feet MSL.

The shallowest water-bearing zone underlying Site ST14 is known as the Upper Zone Aquifer, generally thought to contain ground water under unconfined conditions. Ground water in the Upper Zone Aquifer at Site ST14 is encountered at depths ranging from approximately 6 to 16 feet below bgs, corresponding to a ground water surface elevation ranging from approximately 560 to 572 MSL. Ground water beneath the site occurs predominantly in the deeper sand and gravel units. In some boreholes, ground water was first encountered in deeper sands but the static water level gradually rose to a higher level within the clay, possibly indicating a semiconfined ground water system.

Figure 2.7 is a map of the approximate ground water surface at Site ST14. Ground water flow is generally southeastward toward Farmers Branch. The direction of ground water flow in the Upper Zone is apparently controlled by the elevation of the upper surface of the Goodland Formation. The average hydraulic gradient for Site ST14 has been calculated to be about 0.007 foot per foot (ft/ft) (Radian, 1991). Six slug tests using ground water monitoring wells LF01-1D, LF01-1F, ST14-17J, ST14-17K, ST14-17L, and ST14-17M were performed in the East Area to investigate the hydrogeologic characteristics of the Upper Zone Aquifer. The test data yielded estimated hydraulic conductivities ranging from 1×10^{-5} to 1.2×10^{-2} cm/sec, which are typical of alluvial deposits containing silt-sand-gravel mixtures. Assuming an estimated porosity of 20 percent and based on the hydraulic gradient of 0.007 ft/ft and the range of calculated hydraulic conductivities, the average ground water flow velocity is about 0.2 to 0.3 foot per day. Due to the variability of reported hydraulic conductivity values for the site, additional slug tests are recommended for the Upper Zone Aquifer as part of this demonstration project. This requirement for the additional field testing in downgradient areas is described further in Section 4 of this TSTD/work plan.

2.3 NATURE AND EXTENT OF CONTAMINATION

The following sections summarize existing analytical data on the nature and extent of contamination at or migrating from Site ST14. Data from previous IRP sampling events and several soil gas surveys have been reviewed to estimate the probable nature and extent of contamination at the site.

2.3.1 Soil Gas Data

The results of three soil gas surveys conducted in 1987 (Radian, 1989), 1990 (Radian, 1991), and 1993 (ES, 1993) at Site ST14 both indicate two soil gas plumes, one centered near ground water monitoring well ST14-17M and one between Tanks 1156 and 1157 (Figure 2.8). The largest soil gas plume is on Site ST14B. Soil gas analytical results indicated that JP-4 fuel hydrocarbons are the principal contaminants of concern. No chlorinated solvents were detected. Soil gas samples collected in 1993 from contaminated soils at Site ST14 had high concentrations of total volatile hydrocarbons (TVH), but only low concentrations of ethylbenzene and xylenes.

Although benzene was detected in soil gas during the survey completed in 1987, benzene and toluene were not detected in soil gas samples from the same general area in 1993.

An initial soil gas investigation was conducted in 1987 on Site ST14B to determine areas delineated by total volatile organic concentrations greater than 1,000 parts per million, volume per volume (ppmv). This criterion was identified based on the maximum quantifiable limit of the methods employed in this survey (Radian, 1988 and 1991). The results of this investigation indicated a large soil vapor plume underlying Tanks 1156 and 1157. A soil gas measurement taken immediately north of ST14-17L registered 800 ppmv total volatile organics. This point is not included, however, in the soil gas plume as shown in Figure 2.8 as it falls below the criterion used to delineate soil gas plumes during this survey. The results of the 1990 soil gas survey confirmed the location of a hydrocarbon vapor plume underlying Tanks 1156 and 1157 (Radian, 1991).

The soil gas plume on Site ST14A is smaller in areal extent than that located on Site ST14B. Compound-specific data has also been collected in this area as part of the bioventing pilot test. Laboratory TVH concentrations from samples taken from Site ST14A in 1993 ranged between 21,000 and 28,000 ppmv. Maximum ethylbenzene and toluene concentrations measured during the 1993 sampling event were 7.9 and 21 ppmv, respectively. These soil gas samples also had depleted oxygen concentrations, ranging from 0.8 to 3.8 percent, and high carbon dioxide concentrations, suggesting that significant biological fuel degradation may be occurring in fuel-contaminated soils at the site (ES, 1993). Additional soil gas samples are needed within the source area and in downgradient areas to better characterize the nature and extent of soil gas contamination and to assess the potential risk of soil gas emanating from contaminated media.

2.3.2 Soil Data

No soil samples have been collected at Site ST14B for chemical analysis. However, soil data collected at Site ST14A during discrete sampling events conducted under the various IRP characterization efforts (Hargis and Montgomery, 1983; Radian, 1986, 1989, and 1991) and the bioventing demonstration project (ES, 1993) centered the location of measurable subsurface hydrocarbon contamination near ground water monitoring well ST14-17M (Figure 2.9). Drilling in the unsaturated portion of the Upper Zone deposits, however, generally did not yield materials with visible contamination except in localized areas.

Total recoverable petroleum hydrocarbon (TRPH) and benzene, toluene, ethylbenzene, and xylene (BTEX) soil contamination is widespread at Site ST14A. No chlorinated solvents have been detected. The lateral extent of significant soil contamination is bounded by soil boring SB7 on the north and SB5 on the south. However, the easterly and westerly extent of soil contamination has not been completely defined.

Fuel contamination extends from the surface, or near surface, to a depth of approximately 12 feet bgs, but is most concentrated in the 8- to 11-foot bgs interval. Laboratory results for TRPH in soil samples ranged from less than 10 milligrams per kilogram (mg/kg) at soil borings SB4, SB5, and SB6, to 6,500 mg/kg at VW2 at a

depth of 10 to 11 feet bgs (see Figure 2.9). The distribution of BTEX is similar to that of TRPH, with benzene concentrations ranging from less than 2 micrograms per kilogram ($\mu\text{g}/\text{kg}$) to 67,000 $\mu\text{g}/\text{kg}$ at SB1 (MPBG1) at a depth of 10 to 11 feet bgs. Laboratory results for TRPH and BTEX for all available soil boring locations completed in 1993 at Site ST14A are shown on Table 2.1. Additional soil borings will be required at Site ST14B and to the west and east of Site ST14A to fully define the extent of soil contamination and potential remediation requirements.

2.3.3 Ground Water Data

The distribution of hydrocarbon contamination at Site ST14 suggested by the soil gas surveys and soil data is further supported by ground water quality data from both the 1990 IRP sampling event and a 1994 sampling event conducted by Law Environmental Government Services (in progress). Ground water data from all permanent ground water monitoring wells located within or downgradient of the site have been compiled in Table 2.2 to indicate the probable nature and extent of ground water contamination directly attributable to Site ST14. Several VOCs were detected in the ground water at Site ST14 during these sampling events, including benzene, ethylbenzene, chlorobenzene, and total xylenes. No chlorinated solvents were detected.

Figure 2.10 depicts the probable extent of benzene, the only contaminant to exceed its MCL, in the Upper Zone Aquifer at Site ST14. The maximum concentration of benzene detected in ground water at Site ST14 during the 1990 IRP sampling effort using permanent wells was 16 $\mu\text{g}/\text{L}$ (ST14-17M), which slightly exceeds its MCL of 5 $\mu\text{g}/\text{L}$. Earlier ground water sampling events had reported benzene concentrations as high as 11,000 $\mu\text{g}/\text{L}$, indicating a reduction in source area benzene has already occurred. Concentrations of total BTEX compounds in permanent wells were also reported recently, with a maximum of 338 $\mu\text{g}/\text{L}$ measured at ground water monitoring well ST14-17M. Other than benzene, all VOCs detected in ground water were detected at concentrations significantly below their respective MCLs.

Although ethylbenzene was the BTEX compound most frequently detected in permanent ground water wells at Site ST14 during the 1990 IRP sampling event, the maximum reported concentration of 35 $\mu\text{g}/\text{L}$ in ground water monitoring well ST14-04 was significantly less than its MCL of 700 $\mu\text{g}/\text{L}$ (Radian, 1991). Total xylenes and chlorobenzene were also detected at Site ST14 during the 1990 IRP sampling event. Xylenes were detected in three wells, ST14-03, ST14-04, and ST14-17M. The highest concentration of total xylenes was 300 $\mu\text{g}/\text{L}$ (in ground water monitoring well ST14-17M), which does not exceed the MCL of 10,000 $\mu\text{g}/\text{L}$. Chlorobenzene was detected at a maximum concentration of 38 $\mu\text{g}/\text{L}$ (again at ST14-17M), which is below the MCL of 100 $\mu\text{g}/\text{L}$. Table 2.2 summarizes the analytical data for VOCs at Site ST14 collected during the 1990 sampling event.

It is important to note that detected contaminant concentrations in ground water samples collected in 1990 were lower than concentrations of the same analytes detected during previous investigations. This trend may be the result of normal variability or natural attenuation of these JP-4 fuel constituents in the Upper Zone Aquifer. However, it is also possible that the decrease in contaminant concentrations could be attributed to dilution as a result of abnormally high precipitation and flooding events that immediately preceded sample collection. The resultant increase in infiltration and

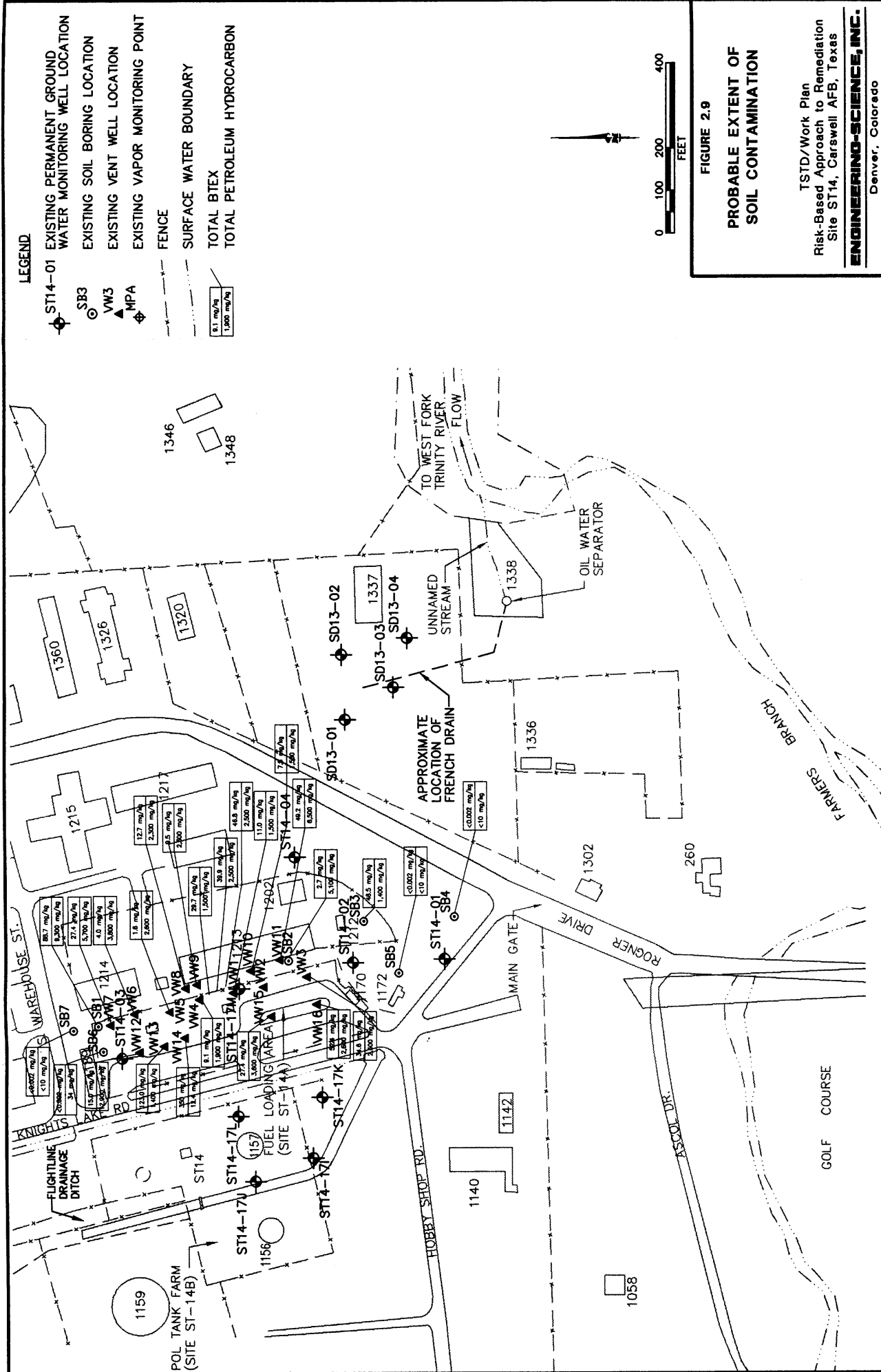


FIGURE 2.9

PROBABLE EXTENT OF SOIL CONTAMINATION

**TSTD/Work Plan
Risk-Based Approach to Remediation
Site ST14, Carswell AFB, Texas**

ENGINEERING-SCIENCE, INC.

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TABLE 2.1

ANALYTICAL RESULTS FROM SOIL SAMPLING PERFORMED IN JUNE 1993
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Parameter:	VW1: 5-6	VW1: 10-11	VW2: 10-11	VW3: 7-8	VW3: 10-11	VW4: 10-11	VW5: 7-8	VW5: 10-11	VW6: 9-10
Benzene ($\mu\text{g/kg}$)	410	270	<200	<2.0	1,000	160	<10	<10	950
Toluene ($\mu\text{g/kg}$)	580	530	19,000	<2.0	12,000	570	380	440	310
Ethylbenzene ($\mu\text{g/kg}$)	790	1,400	5,200	<2.0	3,600	1,500	120	<10	980
Xylenes ($\mu\text{g/kg}$)	4,200	8,800	25,000	4.1	18,000	6,900	410	1,200	1,800
BTEX ($\mu\text{g/kg}$)	5,980	11,000	49,200	4.1	34,600	9,130	910	1,640	4,040
TRPH (mg/kg)	890	1,500	6,500	<10	4,500	1,900	420	2,600	3,800

Parameter:	VW7: 9-10	VW8: 10-11	VW8: ¹ Dup	VW9: 9-10	VW10: 10-11	VW12: 10-11	VW13: 9-10	VW14: 9-10	VW15 11-12
Benzene ($\mu\text{g/kg}$)	<1,000	2,000	1,900	200	470	3,800	<2,000	890	<1,000
Toluene ($\mu\text{g/kg}$)	19,000	2,600	3,400	3,600	740	2,600	54,000	2,900	10,000
Ethylbenzene ($\mu\text{g/kg}$)	3,600	1,200	1,300	910	1,100	2,700	17,000	1,500	3,400
Xylenes ($\mu\text{g/kg}$)	4,800	5,000	6,100	4,800	5,200	5,900	52,000	7,100	14,000
BTEX ($\mu\text{g/kg}$)	27,400	10,800	12,700	9,510	7,510	15,000	123,000	12,400	27,400
TRPH (mg/kg)	5,700	1,900	2,300	1,200	1,500	2,900	1,400	350	3,600

¹ VW8:
Dup is a duplicate of VW8:10-11
² MPGB1:
Also referred to as SB1
³ VW11:
VW11 drilled 5 feet north of SB2
⁴ SB4:
Dup is a duplicate of SB4:10-11

TABLE 2.1 (Continued)

ANALYTICAL RESULTS FROM SOIL SAMPLING PERFORMED IN JUNE 1993
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

	VW16: 9-10	MPA: 9-10	MPB: 9-10	MPC: 6-7	MPC: 10-11	MPBG1: ² 10-11	MPBG2: 10	SB2: ³ 7-8	SB2: 10-11
Parameter:									
Benzene (µg/kg)	2,800	1,800	2,800	<500	<200	67,000	<2.0	3.6	53
Toluene (µg/kg)	11,000	3,700	4,100	2,000	10,000	<5,000	<2.0	4.8	600
Ethylbenzene (µg/kg)	6,600	5,300	7,000	3,700	2,600	14,000	<2.0	7.4	<10
Xylenes (µg/kg)	32,000	36,000	26,000	24,000	17,000	7,700	<2.0	40.0	2,000
BTEX (µg/kg)	52,400	46,800	39,900	29,700	29,600	88,700	<2.0	55.8	2,650
TRPH (mg/kg)	2,600	2,500	2,500	1,100	1,500	9,300	47	<10	5,100
	SB3: 9-10	SB4: 7-8	SB4: 10-11	SB4: ⁴ Dup	SB5: 10-11	SB6: 9-10	SB7: 11-12		
Parameter:									
Benzene (µg/kg)	5,400	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		
Toluene (µg/kg)	15,000	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		
Ethylbenzene (µg/kg)	4,100	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		
Xylenes (µg/kg)	24,000	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		
BTEX (µg/kg)	48,500	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		
TRPH (mg/kg)	1,400	<10	<10	<10	<10	34	<10		

¹ VW8:
Dup is a duplicate of VW8:10-11

² MPGB1:
Also referred to as SB1

TABLE 2.2

ANALYTICAL RESULTS FROM GROUND WATER SAMPLING
PERFORMED BY RADIAN CORPORATION, 1990
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

	ST14-01	ST14-02	ST14-03	ST14-04	ST14-17I	ST14-17J	ST14-17K	ST14-17L	ST14-17M	SD13-01
Parameter:										
Benzene ($\mu\text{g/L}$)	ND ¹	ND	1.3	ND	ND	3.8	0.5	0.7	16	2
Toluene ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	3.7	2.4	ND	22	12
Ethylbenzene ($\mu\text{g/L}$)	0.7	4.3	0.6	35	0.73	1.3	ND	ND	ND	ND
Xylenes ($\mu\text{g/L}$)	ND	ND	0.4	36	ND	ND	ND	ND	300	ND
BTEX ² ($\mu\text{g/L}$)	0.7	4.3	2	71	0.73	8.8	2.9	0.7	338	14
Chlorobenzene ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	ND	ND	0.45	38	ND

	SD13-02	SD13-03	SD13-04	LF01-1A	LF01-1B	LF01-1C	LF01-1D	LF01-1D	LF01-1F
Parameter:									
Benzene ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene ($\mu\text{g/L}$)	ND	59	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylenes ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	ND	ND	ND	ND
BTEX ($\mu\text{g/L}$)	ND	59	ND	ND	ND	ND	ND	ND	ND
Chlorobenzene ($\mu\text{g/L}$)	ND	3.6	ND	ND	ND	0.36	ND	ND	ND

¹ ND = Indicates not detected at listed MDL.² BTEX = Refers to total concentrations of benzene, toluene, ethylbenzene, and xylenes.

TABLE 2.2 (Continued)

ANALYTICAL RESULTS FROM GROUND WATER SAMPLING
PERFORMED BY LAW ENVIRONMENTAL, MARCH 1994
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Parameter:	A100	A400	A700	A900	B100	B200	B500	B800 ¹	B1000	C000	C100
Benzene ($\mu\text{g/L}$)	ND ²	ND	ND	ND	ND	ND	47	3	42	ND	2
Toluene ($\mu\text{g/L}$)	5	5	ND	ND	ND	5	22	6	12	ND	2
Ethylbenzene ($\mu\text{g/L}$)	31	ND	ND	ND	ND	409	18	9	ND	ND	ND
Xylenes ($\mu\text{g/L}$)	37	5	ND	ND	ND	1,089	77	23	7	ND	ND
BTEX ($\mu\text{g/L}$) ³	73	10	ND	ND	ND	1,503	164	41	61	ND	4
TRPH (mg/L) ⁴	ND	5,500	1,900	100	ND	3,600	5,000	1,600	ND	ND	2,400
Parameter:	C200	C500	C800	D200	D700	E0 + 10	E1 + 10	E210	E400	E600	F300
Benzene ($\mu\text{g/L}$)	ND	15	ND	ND	ND	ND	ND	ND	59	ND	ND
Toluene ($\mu\text{g/L}$)	ND	ND	14	ND	ND	ND	ND	ND	69	ND	ND
Ethylbenzene ($\mu\text{g/L}$)	ND	ND	ND	ND	ND	ND	ND	ND	74	ND	ND
Xylenes ($\mu\text{g/L}$)	ND	24	44	ND	ND	ND	ND	ND	62	ND	ND
BTEX ($\mu\text{g/L}$)	ND	39	58	ND	ND	ND	ND	ND	264	ND	ND
TRPH (mg/L)	ND	4,600 ¹	11,000 ⁵	3,600	12,600 ⁵	ND	ND	ND	184,000 ⁵	1,300	ND

¹ Average of duplicate and sample result.² ND = Indicates not detected at listed MDL.³ BTEX = Refers to total concentrations of benzene, toluene, ethylbenzene, and xylenes.⁴ TRPH = Refers to total recoverable petroleum hydrocarbons.⁵ INT = Indicates that interferences prevent accurate determination.

recharge in the local area may have lowered the concentrations of detected constituents (Radian, 1991).

In March 1994, Law Environmental Government Services supervised additional ground water sampling downgradient of Site ST14. The sampling was completed by Transglobal Environmental Geochemistry using a temporary monitoring probe which was hydraulically driven into the first 18 inches of the Upper Zone Aquifer. Samples were retrieved using a peristaltic pump and analyzed with an onsite gas chromatograph using modified EPA Method SW8015. The maximum concentration of benzene detected during this survey was 59 $\mu\text{g/L}$ (E400), which is more than an order of magnitude greater than its MCL of 5 $\mu\text{g/L}$. Benzene concentrations above the MCL were also measured at three other locations at Site ST14: B500, B1000, and C500. No measured concentration of toluene, ethylbenzene, or total xylenes exceeded their respective MCLs. Figure 2.2 also depicts these sampling locations, and Table 2.2 includes analytical results from this characterization effort.

ES also participated in the March 1994 sampling event to collect data necessary to support evaluation of the potential effectiveness of the intrinsic remediation option at the site. Data collected included concentrations of dissolved oxygen, nitrate, nitrite, ferric/ferrous iron, redox, pH, conductivity, and temperature. All sample analysis was performed using field instruments and colorimetric (HACH®) methods approved under the AFCEE intrinsic remediation protocol document (ES, 1994). Table 2.3 presents these physiochemical data by sample location.

Data from the more recent ground water sampling efforts suggest that the downgradient VOC plume may be emanating from more than one source area within Site ST14. The total maximum BTEX concentration from sample location B200 was 1,503 $\mu\text{g/L}$; a maximum benzene concentration of 59 $\mu\text{g/L}$ was detected at sample location E400. The ground water plume associated with Tanks 1156 and 1157 appears to be delineated. No significant contamination was found in ST14-17I to the west, A900 to the south, or A700 to the east. However, given the potential for multiple source areas and the uncertainty with regard to the site-specific direction of ground water flow in this area, further data are necessary to more fully delineate the probable extent of the ground water plume.

Available electron acceptors for *in situ* biodegradation, such as dissolved oxygen and nitrate, are present in the Upper Zone Aquifer, but appear to be depleted in the Site ST14 source area and plume. Additional sampling is required to better define the areal extent of the ground water plume with respect to electron acceptors, and the mass-transport characteristics of the Upper Zone Aquifer within and downgradient of Site ST14. Section 4 summarizes the additional hydrogeologic characterization activities that will be necessary to support the risk-based approach to remediation at Site ST14.

2.3.4 Surface Water Data

Previous surface water sampling data indicated detectable concentrations of benzene and toluene in the Unnamed Stream. During an investigation conducted in 1986, the highest concentration of benzene detected in the Unnamed Stream was 120 $\mu\text{g/L}$, whereas the maximum concentration of toluene was 19 $\mu\text{g/L}$ (Radian, 1991).

TABLE 2.3

INTRINSIC REMEDIATION PROTOCOL PARAMETERS MEASURED DURING
FIELD TESTING BY ENGINEERING-SCIENCE, INC., MARCH 1994
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

	A100	A400	A700	A900	B100	B200	B500	B800	B1000	C000	C100
Parameter:											
Nitrates (mg/L)*	NEG	0.25	0.50	0.20	0.40	4.85	10.6	6.80	8.15	0.00	0.45
Nitrites (mg/L)*	0.072	0.013	0.010	0.050	0.023	0.015	NEG	0.000	0.001	0.017	0.049
Ferrous iron (mg/L)*	0.63	1.49	7.77	+	0.06	6.49	3.45	4.90	8.10	0.18	0.05
Dissolved oxygen (mg/L)	2.0	0.4	1.8	1.2	1.8	0.4	1.1	1.2	0.8	2.4	1.4
Redox potential (mV)	-117.7	-157.6	-89.5	-106.9	+42.9	+8.36	-77.3	-98.2	-108.4	+101.4	+122.4
pH	7.38	6.94	6.84	7.25	7.16	6.57	6.77	6.86	7.0	6.64	7.20
Conductivity (μS/cm)	740	720	780	8,500	640	1,130	1,140	1,010	860	480	710

	C200	C500	C800	D200	D700	E0+10	E1+10	E210	E400	E600	F300
Parameter:											
Nitrates (mg/L)*	0.75	14.05	0.90	NEG	5.55	0.60	NEG	NEG	NEG	NEG	1.40
Nitrites (mg/L)*	0.073	0.005	0.000	NEG	NEG	0.048	0.056	0.085	NEG	NEG	0.009
Ferrous iron (mg/L)*	0.79	8.2	1.00	+	6.05	0.90	0.28	1.52	8.10	1.05	4.27
Dissolved oxygen (mg/L)	1.4	1.0	2.2	1.8	0.4	1.4	0.8	1.6	NS	0.7	0.6
Redox potential (mV)	+24.5	-81.6	-72.6	-89.6	-104.2	-12.7	+61.0	+21.0	-90.6	-123.5	-103.8
pH	7.11	6.81	6.84	6.74	6.44	7.02	6.98	7.14	6.45	7.03	7.01
Conductivity (μS/cm)	900	1,110	1,080	1,240	880	930	910	840	700	940	940

* = Results of nitrates, nitrites, and ferrous iron are the average of two readings.

NEG = Refers to negative reading due to blank being cloudier than test solution.

+ = Indicates sample dilution needed, but not performed.

NS = Not sampled due to insufficient volume.

Four additional surface water samples were collected as part of the 1990 IRP sampling effort at the Unnamed Stream. Orange-colored foam and a rusty film were noted on the surface of the water at the time of sampling. Benzene and toluene were again the most widespread VOCs detected in the surface water samples, although the concentrations were significantly less than those measured previously. The highest concentration of benzene detected in the surface water in 1990 was 0.31 $\mu\text{g/L}$; the maximum concentration of toluene was 0.59 $\mu\text{g/L}$. Concentrations of these contaminants decreased with increasing distance downstream, probably due to volatilization and dilution. Based on this trend, it appears that any natural ground water seepage entering the stream does not contribute significant contaminants. As suspected, the oil/water separator is the primary source of the surface water contamination. Table 2.4 summarizes the 1990 analytical data from these surface water samples.

The decrease in contaminant concentration in surface water from 1986 to 1990 may also be the result of a less concentrated source from the oil/water separator. It is possible, however, that the decrease in contaminant concentrations may be directly attributable to the high flow in the Unnamed Stream during the sampling event as a result of the abnormally high precipitation and flooding that immediately preceded surface water sample collection. Given the uncertainty about the nature and extent of possible surface water contamination that is attributable to Site ST14, Section 4 defines several additional characterization activities designed to provide sufficient data on the nature of ground water routed from the french drain system to the oil/water separator and the resulting impacts to the Unnamed Stream.

2.3.5 Frequency of Free Product

Free-phase JP-4 fuel product has only been observed in one ground water monitoring well at Site ST14. As noted previously, more than 2 feet of free product was observed in ground water monitoring well ST14-17M during the 1990 IRP sampling event. Further, during the May 1993 bioventing tests conducted by ES, a thin free product film was also observed in one bioventing vent well (VW-1) and several vapor monitoring points (MPA, MPB, and MPC). All of these sample locations are within 40 feet of ST14-17M (ES, 1993). Since June 1993, base personnel have performed weekly monitoring of free product levels in well ST14-17M. The average product thickness during this period has been approximately 0.75 inch. More recent preliminary investigation work completed by ES in 1994 in support of the risk-based remediation project for Site ST14 detected only a thin free product film in ground water monitoring well ST14-17M. Section 4 of this TSTD/work plan describes methods to be employed to quantify the existing extent of free product contamination at Site ST14 using proposed and existing bioventing and ground water monitoring wells. If a free product sample can be collected, it will be analyzed for its total BTEX content to determine how the remaining free product is partitioning into the underlying ground water and contributing to the dissolved-phase BTEX plume at Site ST14.

TABLE 2.4
ANALYTICAL RESULTS FROM SURFACE WATER SAMPLING
PERFORMED BY RADIAN CORPORATION, 1990
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Parameter	SD13-S1	SD13-S2	SD13-S3	SD13-S4
Benzene ($\mu\text{g/L}$)	0.26	ND	0.31	0.23
Toluene ($\mu\text{g/L}$)	ND	0.59	ND	ND
Ethylbenzene ($\mu\text{g/L}$)	ND	0.97	ND	ND
Xylenes ($\mu\text{g/L}$)	0.53	ND	0.37	ND
1,2-dichlorobenzene ($\mu\text{g/L}$)	ND	ND	ND	ND
1,3-dichlorobenzene ($\mu\text{g/L}$)	1.2	1.0	ND	ND
1,4-dichlorobenzene ($\mu\text{g/L}$)	ND	1.7	ND	ND
Chlorobenzene ($\mu\text{g/L}$)	0.65	2.8	2.6	1.2

ND = Not detected.

SECTION 3

IDENTIFICATION OF SITE MODELS

In order to demonstrate attainment pursuant to Risk Reduction Standard No. 3, it will be necessary to collect sufficient data to comparatively evaluate the long-term effectiveness of various remedial alternatives at eliminating or minimizing current or potential future risks to human health and the environment. Section 3.1 describes a conceptual site model for Site ST14, which includes possible source and release mechanisms, governing fate and transport processes, potential exposure points and routes, and potential human and environmental receptors. Section 3.2 describes the Bioplume II model which will be used to quantitatively evaluate whether dissolved-phase ground water contamination can migrate to a receptor exposure point. Section 3.3 describes other quantitative contaminant fate and transport models that may be used to evaluate exposure potential from contamination in environmental media other than ground water.

3.1 CONCEPTUAL SITE MODEL

The purpose of developing a conceptual site model (CSM) is to evaluate existing information about the physical characteristics of the site, including potential contaminant sources, chemicals of concern, release mechanisms (e.g., leaching and volatilization), governing fate and transport processes (e.g., molecular diffusion, ground water migration, and direct discharge), potential human and ecological receptors (e.g., current on-base workers, potential future on-base residents, current/future off-base residents, terrestrial and aquatic vegetation and wildlife), exposure points (i.e., locations where receptors could come into contact with site-related contamination), and routes of exposure (e.g., inhalation, ingestion, dermal contact), to identify the types of data necessary to quantify receptor exposure. The CSM will be used to define the nature of additional site characterization activities required at Site ST14 to support identification, selection, and implementation of a final remedial alternative that complies with the technical requirements of Risk Reduction Standard No. 3 (TNRCC, 1993). The CSM constructed for Site ST14 is shown schematically in Figure 3.1.

3.1.1 Definitions

It is appropriate at this point to define some of the key terms used in the risk-based approach to remediation. A *risk assessment* is the quantitative estimation of a hazard. A *baseline risk assessment* estimates the hazards that might exist if no remediation or institutional controls were applied at a site. A *conceptual site model* (CSM) qualitatively identifies how potential human and ecological receptors could come into

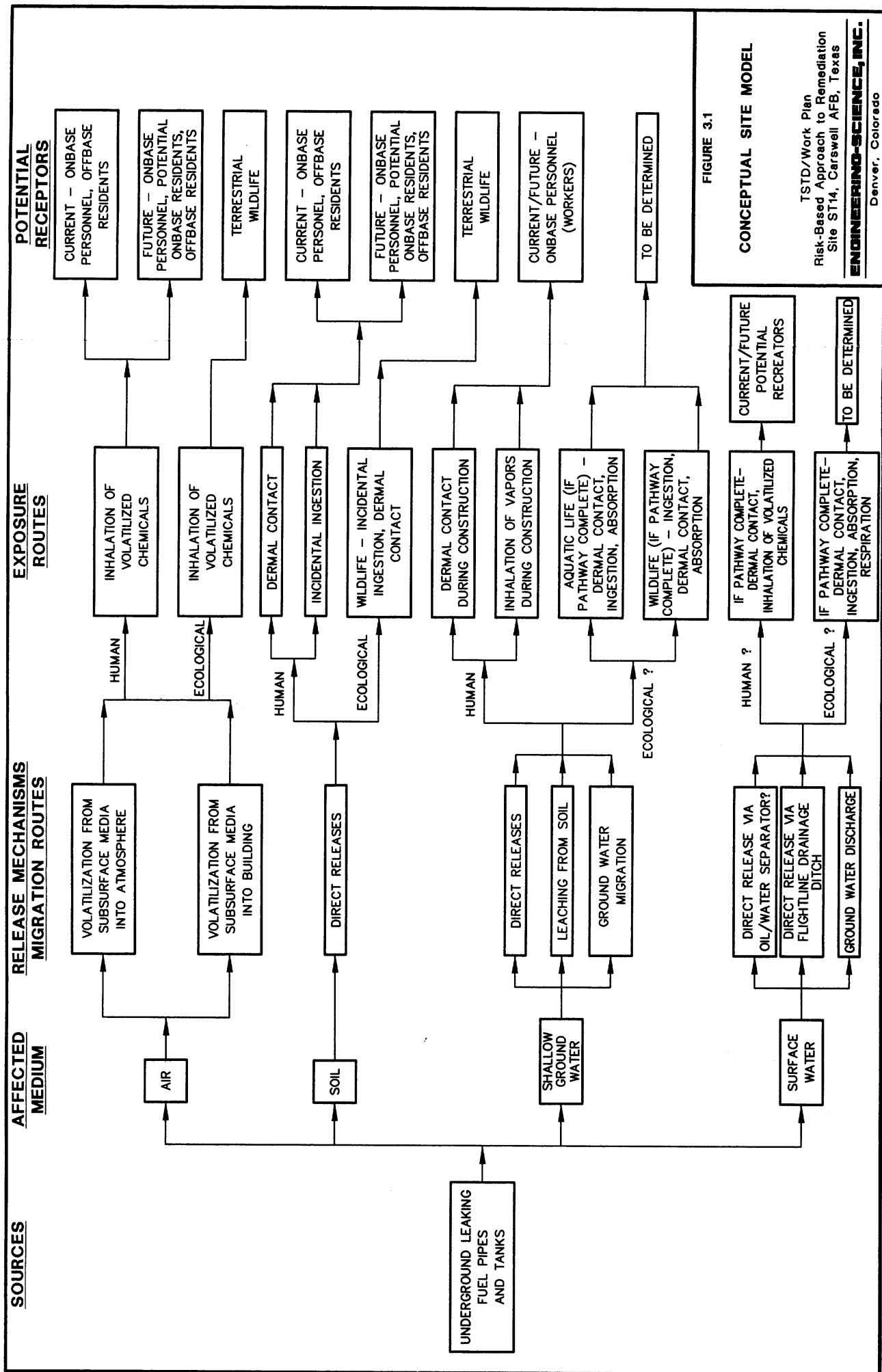


FIGURE 3.1

CONCEPTUAL SITE MODEL

TSTD/Work Plan
 Risk-Based Approach to Remediation
 Site ST14, Carswell AFB, Texas
ENGINEERING-SCIENCE, INC.
 Denver, Colorado

contact with site-related contamination. A CSM is then used to assess data needs and guide data collection and analysis efforts. An *exposure assessment* involves estimating the type and magnitude of receptor exposures to contaminants of concern (COCs) that are present at or migrating from a site. Contaminants of concern (COCs) are chemicals that are potentially site-related and whose data are of sufficient quality for use in a quantitative risk assessment. A *risk assessment concentration* or *exposure point concentration* is the highest concentration a potential receptor would reasonably be expected to contact. The risk-based approach to remediation uses conservative quantitative models that account for the effects of fate and transport processes to estimate exposure-point concentrations. The probable effectiveness of intrinsic remediation and other innovative source removal technologies such as bioventing to reduce exposure-point concentrations will also be determined using conservative quantitative models.

Contaminant screening levels are conservative risk-based or promulgated criteria used to identify and screen out areas or environmental media that do not warrant further study. *Chemical-specific remediation goals* define the "acceptable" concentration of chemicals that can remain onsite following remediation and still meet remedial action objectives. These cleanup goals can either be risk-based or based on promulgated criteria. *Risk-based remediation goals* (remediation goals) are long-term target concentrations for environmental media based on target risk levels, toxicity information, and exposure equations rather than on promulgated cleanup standards. Remediation goals will be used to identify, select, and design an appropriate remedial alternative that will minimize or eliminate risks due to exposure to site-related contaminants. Remediation goals will be developed using site-specific land use assumptions, the procedures outlined in EPA Office of Solid Waste and Emergency Response (OSWER) Directive 9285.7-01B entitled *Human Health Evaluation Manual, Part B: Development of Risk-based Remediation Goals*, and the procedures concerning medium-specific concentrations (MSCs) outlined in Section 335.553 of TNRCC's risk reduction rules. These remediation goals may be modified to address technical limitations, effectiveness, practicability, or other relevant considerations, including reasonable expected future exposure conditions at the site not already incorporated into the cleanup levels. These final cleanup goals are compared to the exposure-point concentrations developed using the quantitative fate and transport models to estimate the type and magnitude of remediation required to protect human health and the environment. More details on the proposed risk analysis methods are presented in Section 5 of this TSTD/work plan.

3.1.2 Previous Risk Estimates

A baseline risk assessment has been completed for Site ST14 using the 1990 IRP analytical data and the 1986 EPA risk assessment guidance which has since been superseded (Radian, 1991). Interestingly, even though both carcinogenic and noncarcinogenic human health risks associated with Site ST14 were shown to be below levels warranting remedial action, the site was designated a high-priority site in the draft Remedial Investigation (RI) Report because it may represent a direct contaminant source or contaminant migration pathway to Farmers Branch and/or the Trinity River. Because the baseline risk assessment cited significant uncertainty about the processes involved in subsurface contaminant transport, the Air Force opted to pursue a risk-

based remediation at Site ST14. Data gaps identified during the baseline risk assessment are addressed in the CSM and in the additional characterization work proposed for Site ST14.

Possible release mechanisms from hydrocarbon contamination in soil considered in the baseline risk assessment for Site ST14 included volatilization to air, fugitive dust generation, leachate to ground water, surface runoff, direct release to surface water, and contaminated ground water discharge to surface water. Fate and transport mechanisms considered included molecular diffusion through unsaturated soil, air dispersion, ground water migration, ground water discharge to and transport in surface water, and plant and animal uptake. Much of the fate and transport data used in the earlier baseline risk assessment for Site ST14 appear to be qualitative and based on best professional judgment in the absence of sufficient data on how contaminants may migrate in the subsurface environment. The CSM developed in this section makes use of the data developed from the baseline risk assessment and other existing information about Site ST14.

3.1.3 Contaminants of Concern

This risk-based demonstration project will address the specific chemical constituents that may drive potential risks and impact the final remedial design for Site ST14. The COCs depend upon the nature of the source (i.e., a JP-4 jet fuel), the affected media (i.e., soil gas, vadose soil, phreatic soil, ground water, and possibly surface water), and the fate, transport, toxicity, and regulatory status of various JP-4 jet fuel constituents. Details on the chemical composition of JP-4 and the physiochemical properties of these compounds are important factors that may influence fate and transport and therefore desired remediation goals for the site.

The major component categories in JP-4 are n-alkanes, branched alkanes, cycloalkanes, benzenes, alkylbenzenes, and naphthalenes. The approximate distribution by weight of these major components by compound category is: alkanes, 32 percent; branched alkanes, 31 percent; cycloalkanes, 16 percent; benzenes and alkylbenzenes, 18 percent; and naphthalenes, 3 percent. Other non-hydrocarbons are not important components in JP-4 by weight.

The environmental behavior of each group of specific hydrocarbons must be considered when identifying COCs for Site ST14. For example, some compounds may be relatively mobile and non-persistent in soil. These compounds may leach effectively from contaminated soil into underlying ground water and migrate as a dissolved-phase plume. Conversely, other compounds may be immobile under unsaturated conditions and not contribute to ground water contamination. Thus, based on the physiochemical properties of each JP-4 constituent, the relative concentration of each will vary with time and distance from the source of contamination. This effect is commonly called weathering.

Partitioning of chemical constituents from free phase and residual contamination is an important mechanism of weathering that should be evaluated when identifying those compounds most likely to pose a risk to potential receptors and require remediation. In general, migration of JP-4 through soils may be retarded to some extent. Once the JP-4 reaches ground water, however, the water solubility of each chemical constituent governs how it partitions into ground water. A fuel/water partition coefficient (K_{FW})

can be used to estimate the maximum concentration in ground water as a result of free phase JP-4 contamination. Available K_{FW} data support the observation that light aromatics such as the BTEX compounds represent the greatest fraction of JP-4 that could impact ground water quality (see Table 3.1). Thus these compounds may be transported and dissolved in ground water.

Because JP-4 is composed of C_{14} and lighter hydrocarbons, it is likely to be significantly weathered where encountered at this site. Chlorobenzene has been detected at Site ST14 under previous investigations. No other chlorinated organic compounds have been detected at this site (see section 2 of this TSTD/work plan). Naphthalene is the only polyaromatic hydrocarbon (PAH) that could be present at the site. Previous characterization efforts did not analyze for this specific compound.

When establishing potential COCs for a site, it is also important to consider the availability and magnitude of toxicity values for each of the JP-4 constituents. Table 3.1 also identifies those compounds of a typical JP-4 sample for which accepted toxicity values are available (e.g., from the Integrated Risk Information System, IRIS). No toxicity data nor promulgated standards are available for most of the specific chemical compounds that could be present in JP-4. Toxicity values are available for the BTEX compounds and naphthalene.

Thus, the COCs for soil gas, soil, ground water, and surface water at or migrating from Site ST14 which will be addressed as part of this demonstration project include the BTEX compounds, naphthalene, and possibly chlorobenzene. Any free fuel product and a limited number of ground water samples taken during the field work phase of this project will be screened for naphthalene and chlorobenzene. This approach is consistent with the baseline risk assessment for Site ST14, which used benzene and toluene as indicator COCs. However, this risk-based demonstration project will focus on all of the JP-4 fuel-related compounds that may impact risks and the effectiveness of a final remedial design for Site ST14.

3.1.4 Potential Source Areas and Release Mechanisms

As noted in Section 2, existing analytical data suggest that more than one contaminant source may exist within Site ST14. Additional site characterization efforts are recommended as part of this demonstration project to more fully delineate discrete source areas within Site ST14. This detail is necessary to facilitate quantitative analyses of fate and transport processes and evaluation and design of an appropriate remedial action for the site. The baseline risk assessment did not identify discrete source areas other than the fuel lines and tanks within Site ST14 (Radian, 1991).

The contaminant release mechanisms incorporated into this conceptual site model are as follows: (1) volatilization into the atmosphere, (2) partitioning from soil or free product into ground water, (3) direct release into surface water via the french drain and oil/water separator system and the Flightline Drainage Ditch, and (4) indirect release to surface water via ground water inflow. This approach is consistent with that followed in the baseline risk assessment except that fugitive dust generation and surface runoff will not be considered to be a significant release mechanisms given that the general depth of contamination is more than 4 feet bgs.

TABLE 3.1
SUMMARY OF FUEL/WATER PARTITIONING COEFFICIENTS
AND AVAILABILITY OF TOXICITY DATA
FOR THE MAJOR COMPONENTS OF JP-4
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Fuel Component	% by Weight	Fuel/Water Partition Coeff.	Available Tox. Data?
Benzene	0.5	231	YES
Toluene	1.33	895	YES
Ethylbenzene	0.37	3410	YES
o-xylene	1.01	3160	YES
m-xylene	0.96	3530	YES
p-xylene	0.35	2960	YES
Napthalene	0.5	24000	YES
1,1,3-trimethylcyclohexane	0.48	651000	NO
1,2,3,4-tetramethylbenzene	0.75	45800	NO
1,2,3-trimethylcyclopentane	0.25	276000	NO
1,2,4-trimethylbenzene	1.01	12270	NO
1,2,4-trimethylcyclopentane	0.25	276000	NO
1,2-dimethyl-4-ethylbenzene	0.77	45800	NO
1,3,5-trimethylbenzene	0.42	6490	NO
1,3,5-trimethylcyclohexane	0.99	651000	NO
1,3-diethylbenzene	0.46	45800	YES
1,3-dimethyl-5-ethylbenzene	0.61	45800	NO
1,4-dimethyl-2-ethylbenzene	0.7	45820	NO
1-methylnapthalene	0.78	27000	NO
1-methyl-2-ethylbenzene	0.23	7710	NO
1-methyl-2-ethylcyclohexane	0.39	9360	NO
1-methyl-2-isopropylbenzene	0.29	35100	NO
1-methyl-3-ethylbenzene	0.49	12200	NO
1-methyl-3-ethylcyclohexane	0.17	9366	NO
1-methyl-4-ethylbenzene	0.43	6690	NO
1-methyl-4-ethylcyclohexane	0.48	9360	NO
1-methyl-4-propylbenzene	0.4	45800	NO
2,2,3,3-tetramethylbutane	0.24	509000	NO
2,2-dimethylbutane	0.1	37800	NO
2,2-dimethylhexane	0.71	509000	NO
2,2-dimethylpentane	0.25	37000	NO
2,4-dimethylhexane	0.58	509000	NO
2,5-dimethylheptane	0.52	1860000	NO
2,5-dimethylhexane	0.37	509000	NO
2,6-dimethylnapthalene	0.25	593000	NO
2,6-dimethylundecane	0.71	333000000	NO
2-methylheptane	2.7	1330000	NO
2-methylhexane	2.35	430000	NO

TABLE 3.1 (Continued)
SUMMARY OF FUEL/WATER PARTITIONING COEFFICIENTS
AND AVAILABILITY OF TOXICITY DATA
FOR THE MAJOR COMPONENTS OF JP-4
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Fuel Component	% by Weight	Fuel/Water Partition Coeff.	Available Tox. Data?
2-methylnaphthalene	0.56	31000	NO
2-methyloctane	0.88	2460000	NO
2-methylpentane	1.28	61900	NO
2-methylundecane	0.64	127000000	NO
3,3-dimethylhexane	0.26	509000	NO
3,4-dimethylheptane	0.43	1860000	NO
3-methylheptane	3.04	1650000	NO
3-methylhexane	1.97	270000	NO
3-methyloctane	0.79	2450000	NO
3-methylpentane	0.89	66350	NO
4-ethylheptane	0.18	2450000	NO
4-methylheptane	0.92	647000	NO
4-methyloctane	0.86	15100000	NO
cis-1,2-dimethylcyclopentane	0.34	16600	NO
cis-1,3-dimethylcyclohexane	0.42	160000	NO
cis-1,3-dimethylcyclopentane	0.54	16600	NO
Cyclohexane	1.24	11700	NO
Dimethylcyclohexane	0.43	160000	NO
Ethylcyclopentane	0.26	16600	NO
Isobutane	0.66	14300	NO
Isopropylbenzene	0.3	9040	YES
Methylcyclohexane	2.27	55300	NO
Methylcyclopentane	1.16	16600	NO
n-butane	0.12	11000	NO
n-butylcyclohexane	0.7	35200	NO
n-decane	2.32	644000000	NO
n-dodecane	2	786000000	NO
n-heptane	3.67	365000	NO
n-hexane	2.21	91000	YES
n-nonane	2.25	7160000	NO
n-octane	3.8	2020000	NO
n-pentane	1.06	18800	NO
n-propylbenzene	0.71	7090	NO
n-tetradecane	0.73	1800000000	NO
n-tridecane	1.52	488000000	NO
n-undecane	2.32	644000000	NO
trans-2,3-dimethylcyclopentane	0.36	16600	NO

Although the baseline risk assessment acknowledged that contamination such as benzene from Site ST14 could pass through the french drain and oil/water separator, the baseline risk assessment did not fully examine nor include the possibility of direct discharge of COCs into surface water via this subsurface collection system or the Flightline Drainage Ditch, both of which may be intercepting contaminated ground water originating from Site ST14. Potential direct discharge of COCs into surface water is incorporated into this CSM to ensure that data collection and quantitative fate and transport calculations using Bioplume II consider this subsurface ground water collection system. Section 4 contains further details on the field tests required to investigate whether ground water from Site ST14 is intercepted by either the french drain system or the Flightline Drainage Ditch, and, if so, what impact this system may have on contaminant migration immediately downgradient of Site ST14.

3.1.5 Fate and Transport Processes

Fate and transport processes included in the CSM are: (1) molecular diffusion through unsaturated soil, (2) air dispersion, (3) ground water migration, and (4) ground water discharge to and transport in surface water. Plant uptake of contamination from soil and surface water and subsequent transport through food chain pathways is not considered a significant fate and transport process for volatile compounds. The BTEX compounds and naphthalene are not considered persistent in biota; there is limited risk due to food chain dynamics. Further, there is no data on the toxicity of these compounds for plants, suggesting again that these compounds do not bioaccumulate or bioconcentrate. The potential fate and transport of the semi-volatile chlorobenzene via plant and animal pathways will only be addressed if data confirm the chemical's presence at potential exposure points and it is bioavailable. These processes are identical to those considered in the baseline risk assessment.

Based on the acknowledged uncertainty about fate and transport processes that could impact how contaminants migrate from Site ST14, this field test will seek to quantitatively evaluate these fate and transport processes to ensure that the final remedial action developed for the site minimizes contaminant migration and the associated risks due to exposure to site-related contamination. The risk reduction rule developed by TNRCC expressly states that sound scientific principles, including contaminant fate and transport processes, must be considered when developing appropriate final cleanup goals for each environmental medium and evaluating the effectiveness of various remedial alternatives for the site.

All the COCs to be considered for Site ST14 readily volatilize from water into air. In fact, the baseline risk assessment developed for Site ST14 presented a chemical emission rate for benzene from unsaturated soils into the air of 1.2×10^{-3} grams/second, which could result in significant airborne contamination. However, the presence of clays in the shallow soil at Site ST14 may also effectively limit upward diffusion of contamination as soil gas. The actual rate of emission from source soils at the site will be investigated as described in Section 4 of this TSTD/work plan, and possibly modeled using the methods described in Sections 3.3 and 5.

The COCs for Site ST14 are also expected to partition from contaminated unsaturated soil, which contains fuel residuals, or from free-phase fuel floating on the ground water surface into the underlying ground water, and migrate downgradient as a

dissolved-phase plume. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, adsorption), these dissolved-phase contaminants will be slowly removed from the ground water system by other naturally-occurring destructive attenuation mechanisms, such as biodegradation, abiotic oxidation, and hydrolysis. The effects of these fate and transport processes on the dissolved-phase ground water plume will be investigated using a quantitative ground water and solute-transport model such as Bioplume II. The potential impact of the french drain system and the oil/water separator will be included in these evaluations. Data collection and analysis requirements are discussed in Sections 4 and 5 of this TSTD/work plan, respectively.

3.1.6 Potential Human and Ecological Receptors

Assumptions about land use form the basis for identifying potential receptors and potential exposure pathways. EPA (1991c) and TNRCC (1993) advise that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be addressed in risk-based remedial decisions. Although hypothetical future residential land use provides the most conservative risk estimates, EPA risk assessment guidance materials state that this conservative approach may not be justifiable if the site is surrounded by an operating industrial facility that can be reasonably assumed to remain as an industrialized area. In these cases, the EPA recommends using other exposure scenarios, such as agricultural or light commercial/industrial, including a qualitative assessment of the likelihood that the assumed reasonable future land use will occur (55 *Federal Register* 710).

Portions of Carswell AFB are scheduled for transfer to civilian authorities. Given the attractive physical characteristics of some portions of the East Area of Carswell AFB, it is possible that some type of residential development may occur in limited areas downgradient from Site ST14, most likely to the south and east of Rogner Drive (Figure 2.2). It is important to note that the residential criteria are intended to be protective of any future uncontrolled land use, not just human habitation. This broad interpretation means that no controls would be imposed on any activity. While this is the most conservative (health-protective exposure scenario), it is not reasonable and representative of the likely future uses of most of Site ST14 and downgradient environs. It is probable that the area north and west of Rogner Drive will not be available for residential development, but will be maintained as an industrial property. Carswell AFB could reasonably apply more stringent land use restrictions or institutional controls to source areas and areas of higher contamination. In this case, this area should be conservatively evaluated using the light industrial/commercial worker exposure scenario.

Further, the exposure assumptions involving ground water usually incorporated into the residential exposure scenario do not represent current or potential future exposure conditions at the site. Shallow ground water is not currently used on-base to meet potable water demands. Further, shallow ground water is not currently used off-base to meet potable water demands. The only source of potable water in the Fort Worth area Lake Worth, located upgradient of Site ST14. No ground water or surface water is used for domestic purposes (Radian, 1991). It is reasonable that any future residential development of portions of Carswell AFB, including environs downgradient

of Site ST14, also would be connected to city water lines. It is unlikely that ground water wells would be used as sources of potable water for these potential future residents. However, this exposure assumption will be confirmed by determining whether civilian authorities can meet expanding residential water demands should this area be opened for future development. Carswell AFB and ES intend to provide sufficient evidence to justify establishing the risk-based remediation goals to reflect the reasonable maximum exposure conditions for Site ST14 and downgradient areas (e.g., no shallow ground water use). Therefore, potential risks to both current and future receptors will be evaluated based upon the likely use of the land in question (i.e., ground water is not a potable source). Restricting certain activities on portions of Site ST14 may be necessary as part of the remediation approach to protect human health and the environment.

Current human receptors for contamination from Site ST14 are assumed to include individuals working or residing in nearby areas at Carswell AFB, particularly those located downwind of Site ST14. Site ST14 is close to base office buildings and occupied work areas, and to off-base residential areas on the east side of the West Fork of the Trinity River and bordering State Highway 183. Potential future human receptors will include both on-base industrial/commercial workers for Site ST14 source areas and on-base and off-base residents for downgradient areas, and may be expanded to include other types of receptor exposures (e.g., recreators using surface water; agricultural use of surface water).

Ecological receptors may include the following: (1) aquatic organisms in Farmers Branch or the Trinity River, and (2) terrestrial organisms that may uptake or ingest surface water from Farmers Branch or the Trinity River. Although this approach is consistent with that used in the baseline risk assessment, it is likely that a more detailed analysis of the fate and transport processes will indicate that exposure pathways to most of these ecological receptors are incomplete. First, as noted previously, Lake Worth is the sole source of potable water in the area. Further, ground water migration to or direct discharge into surface water may represent an incomplete or insignificant migration pathway. The migration pathways will be fully evaluated as part of this demonstration project to clearly identify only complete exposure pathways from affected media to receptors. Finally, although ground water is used to irrigate crops in the area (South, 1988), the baseline risk assessment precluded possible contaminant migration or transport to any domestic or agricultural use wells in the area based on the natural hydrogeologic conditions that prohibit significant vertical migration through the Goodland Formation and beyond the Trinity River or Farmers Branch, which are ground water divides. Second, even if the data indicate that the COCs are transported to a potential exposure point, the chemicals may not be bioavailable. Available toxicity data for plants and animals do not suggest that volatile organic compounds such as the BTEX compounds and naphthalene can be bioaccumulated or bioconcentrated.

Section 4 of this TSTD/work plan outlines what information will be gathered to confirm local ground water use assumptions. Section 4 of this TSTD/work plan also identifies the need to obtain additional data on potential ecological receptors to determine what populations, if any, could be exposed to site contamination in the event that an exposure pathway were complete.

3.1.7 Exposure Points and Exposure Routes

An exposure point is a location at which any potentially exposed receptor could come into contact with site-related contamination. On-base contaminated media will be considered possible exposure points only for those base personnel who currently have access to Site ST14 and for potential future residents should the area be opened for civilian development. Potential exposure points initially included in this CSM include Site ST14 and the environs immediately downgradient likely to be affected by contamination at or migrating from any source areas, nearby base office buildings and occupied work areas, off-base residential areas on the east side of the West Fork of the Trinity River and bordered by State Highway 183, Farmers Branch, and the Trinity River. Several of these potential exposure points may be eliminated from the final evaluation should the fate and transport data demonstrate that site-related contamination could not reach these locations (i.e., the exposure pathway is incomplete).

Probable exposure routes are dependent upon which receptors come into contact with what contaminated media. Exposure routes considered for human receptors in this CSM are limited to inhalation of contaminants volatilizing from soil or surface water, inhalation of VOCs accumulating within structures, incidental ingestion of contaminated soil (as particulates), and dermal contact with contaminated soil, surface water, and possibly ground water at the oil/water separator. Any direct exposure routes involving ground water as a potable or domestic source will not be included as possible exposure routes for the reasons described previously. Probable exposure routes for ecological receptors will be limited to direct routes only; that is, routes of exposure for ecological receptors may include inhalation of contaminants volatilizing from surface soil or surface water, ingestion of contaminated surface water, and dermal contact with contaminated soil, sediment, and surface water. As noted previously, however, it is possible that many of the ecological exposure pathways may be incomplete. Further quantitative information on ground water migration and the effect of the french drain system and the Flightline Drainage Ditch on contaminant transport are required.

3.1.8 Target Remediation Goals

The risk analysis approach to be used to screen, evaluate, select, design, and implement the most cost effective remedial alternative at the site is shown in Section 5 of this TSTD/work plan (Figure 5.1). In general, a three-tiered approach will be pursued involving (1) trigger or "evergreen" levels, (2) initial quantitative exposure assessment and chemical-specific remediation goals, and (3) more complex quantitative exposure assessment and chemical-specific remediation goals which includes partial source removal.

Site specific concentrations will first be compared to "evergreen" cleanup goals as an initial step to determine if continued investigation of remedial alternatives is warranted. If this comparison indicates the need for a more site-specific analysis (i.e., generic trigger levels are exceeded), then a quantitative exposure assessment designed to investigate governing fate and transport mechanisms and the potential effectiveness of intrinsic remediation (see Section 3.2) will be completed. Results of this evaluation will be compared to site-specific remediation goals rather than "evergreen" levels to assess whether intrinsic remediation coupled with long-term monitoring will be

sufficient to protect human health and the environment. If this second analysis suggests the need for additional remediation to meet cleanup goals for the site, the remedial alternative evaluation will be expanded to include an iterative, quantitative analysis of the effectiveness of other remedial technologies such as bioventing.

The goal of this tiered approach is to quickly identify which media and COCs may or will pose a risk to receptors so that a remedial alternative can be developed to minimize or abate these risks. Section 5 of this TSTD/work plan contains a more detailed description of the risk analysis methods to be used in this demonstration project. The following sections briefly discuss several concepts that may drive the development of chemical-specific remediation goals for Site ST14, and guide the risk analysis for demonstrating attainment with Risk Reduction Standard No. 3.

The first step in the tiered approach is comparing site concentrations to levels that would not trigger further action. Chemical-specific screening levels (formerly known as trigger levels) are MSC levels defined by EPA or some other promulgated standard that can be used to quickly identify contaminated media that require further investigation and eliminate other media that do not warrant additional study (e.g., EPA, 1993). Using chemical-specific screening levels at this first step focuses data collection and analysis on those chemicals, media, and areas within a site that may warrant concern, and eliminates unnecessary and costly investigation efforts. These chemical-specific screening levels are often called "evergreen" as they mark levels below which few people would argue about the need for remediation, regardless of site-specific circumstances. However, concentrations in environmental media that exceed these chemical-specific "evergreen" screening levels do not automatically designate the site as "dirty" or trigger the need for a response action. Exceedances only indicate the need for further study to establish whether site-specific concentrations are protective of human health and the environment (EPA, 1993).

Table 3.2 presents the soil-specific screening (evergreen) levels for the COCs assuming unrestricted residential land use at Site ST14. These soil screening levels are designed to be protective of human health. Development of soil "evergreen" levels that are protective of ground water quality (commonly called cross-media contamination levels) presume human ingestion at some close downgradient point. As this is not an appropriate nor representative exposure assumption for Site ST14 given current or probable future exposure conditions at the site, these soil levels represent the most conservative or "worst case" screening levels. Chemical-specific screening levels most appropriately applied to this site would be designed to protect some other environmental quality, such as surface water at the point of discharge, based on fate and transport calculations.

In any event, these soil "evergreen" levels can still be used to determine which soils at Site ST14 do not warrant additional study under even the most conservative exposure assumptions. If concentrations in specific environmental medium at Site ST14 do not exceed "evergreen" levels, no further study or remedial action is warranted. Comparison of "evergreen" soil benzene values to the soil contamination levels presented on Figure 2.9 indicate the need for additional study to quantify site-specific release and transport mechanisms and to develop final concentration goals that are protective of human health and the environment. Further, as noted previously, benzene exceeded its "evergreen" ground water level (its MCL) of 5 $\mu\text{g/L}$ at several locations,

TABLE 3.2
SUMMARY OF SOIL AND GROUND WATER "EVERGREEN" LEVELS
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Parameter	Soil (Inhalation) (mg/kg)	Soil (Ground Water Protection) (mg/kg)	Ground Water MCLs (μ g/L)
Benzene	3.2	0.1	5
Toluene	330	36	1,000
Ethylbenzene	330	33	700
Xylenes	100	570	10,000
Napthalene	3100	250	--
Chlorobenzene	320	5	100

Source: EPA, 1993, OSWER Soil Screening Levels
56 *Federal Register* 20 (1/30/91)

suggesting the need for more evaluation. The risk-based approach to remediation for Site ST14 has been designed to satisfy these data objectives.

Chemical-specific concentration goals are remediation goals for individual chemicals for specific medium and land use combinations. Concentration goals are more site-specific than "evergreen" screening levels in that they reflect site-specific conditions. These goals are necessary to identify, evaluate, and select an appropriate remedial alternative for Site ST14. Identification of these chemical-specific, site-specific criteria depend upon which chemicals are present at the site, which environmental media are or may become contaminated, land use assumptions, and any exposure assumptions used to develop or identify the chemical-specific, site-specific remediation goals. For example, chemical-specific remediation goals developed for Carswell AFB may include a fate and transport model component so that the cleanup goal can be met at an exposure point rather requiring all media at the site to be remediated to this level. Final chemical-specific, site-specific concentration goals for Site ST14 will be based on current and future exposure assumptions most appropriate for the site. This approach is consistent with that recommended for demonstrating attainment under Risk Reduction Standard No. 3 (TNRCC, 1993).

Chemical-specific concentration goals can either be risk-based or based on promulgated criteria. This demonstration will develop risk-based human health remediation goals for each COC for each contaminated environmental medium (e.g., vadose zone soil, ground water) using carcinogenic and/or noncarcinogenic toxicity values, land-use assumptions, and exposure assumptions. Risk-based remediation goals are calculated only for human receptors. Human health remediation goals may also be developed from appropriate promulgated standards. Ecological remediation goals, if necessary, will be developed using standards-based criteria rather than toxicity-based criteria. Further details on how site-specific remediation goals will be developed for Site ST14 are presented in Section 5 of this TSTD/work plan.

3.2 INTRINSIC REMEDIATION AND THE BIOPLUME II MODEL

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and whether any exposure pathway for human or ecological receptors is complete. The Bioplume II model has proved useful for predicting BTEX plume migration and contaminant attenuation by natural biodegradation. The Bioplume II model (Rifai et al., 1988) can be used to evaluate critical ground water fate and transport processes that may involved in some of the migration pathways to human and ecological receptors. Other quantitative models potentially suitable to simulate fate and transport in soil, air, and surface water are presented in Section 3.3 of this TSTD/work plan. More representative remediation goals that are protective of human health and the environment can be developed by quantitatively incorporating fate and transport processes into the evaluation of potential risks due to exposure to site-related contamination. Quantitative fate and transport analyses and risk calculations can then be coupled to determine what level and extent of remediation is required. These calculations can also be useful in developing and negotiating final concentration goals that are protective of human health and the environment given the site-specific conditions.

An important consideration in determining whether fuel hydrocarbon contamination presents a substantial threat to human health and the environment, and what type of remedial alternative will be most cost effective for eliminating or abating the threats posed by this fuel hydrocarbon-contaminated site, is an accurate estimate of the potential for natural biodegradation of BTEX compounds in the soil and ground water. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons (Lee et al., 1988). This process occurs naturally when sufficient oxygen, other electron acceptors such as nitrate and sulfate, and nutrients are available in the soil and ground water. The rate of natural biodegradation is generally limited by the lack of electron acceptors rather than by the lack of nutrients such as nitrogen or phosphorus.

Biodegradation of fuel hydrocarbons occurs when microorganisms catalyze the transfer of electrons from electron donors to electron acceptors during respiration. Electron donors can be organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons can be completely degraded or detoxified if they are used as the primary electron donor for microbial metabolism. Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, sulfate, manganese, ferric iron, and carbon dioxide. Microorganisms preferentially use electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). Dissolved oxygen is used first as the prime electron acceptor. However, once the available oxygen is depleted and anaerobic conditions dominate the subsurface, anaerobic microorganisms can use other electron acceptors in the following order of preference: nitrate, sulfate, manganese, ferric iron, and finally carbon dioxide.

The supply of oxygen to unsaturated soil is constantly renewed by the vertical diffusion from the atmosphere. The supply of oxygen and other electron acceptors to a shallow, fuel-contaminated aquifer is constantly renewed by the influx of upgradient flow and the vertical diffusion of oxygen from the unsaturated soil zone into the ground water (Borden and Bedient, 1986). The rate of natural biodegradation in unsaturated soil and shallow aquifers is largely dependent upon the rate at which oxygen and other electron acceptors enter the contaminated media.

3.2.1 Biodegradation of Soil Contamination

The rate of vertical diffusion of oxygen into unsaturated, contaminated soil is a function of both the air permeability of the soil and the concentration gradient between the ambient atmosphere and the soil. In general, downward natural diffusion processes are rate-limiting and do not substantially enhance potential natural biodegradation processes within unsaturated soils. Natural biodegradation is not expected to rapidly reduce soil contamination. It is possible, however, to optimize both of these conditions by introducing oxygen into the unsaturated soil via a low-rate injection system. This innovative technology, called bioventing, supplies oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons. The radius of influence of each injection system point depends upon the operational parameters of the engineered bioventing system and the physical, chemical, and biological characteristics of the contaminated, unsaturated soil. The positive influences of oxygenating shallow unsaturated soil are considered an engineered source removal technology. Results of the bioventing pilot testing at Site ST14A are described in Section 4 of this TSTD/work plan.

3.2.2 Biodegradation of Dissolved-Phase Contamination

Several well-documented and widely-accepted numerical models are available for modeling the fate and transport of fuel hydrocarbons under saturated conditions and accounting for the influences of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. The positive effect of these processes on reducing the actual mass of fuel-related contamination dissolved in ground water has been termed intrinsic remediation. In some cases, intrinsic remediation will reduce the dissolved-phase contaminant concentrations to below concentration levels warranting remedial action (i.e., trigger or screening levels), even if little or no source removal/reduction is implemented. In situations where intrinsic remediation will not reduce contaminant concentrations to below these levels, it may be possible to negotiate less stringent, site-specific final remediation goals that are still protective of human health and the environment given the type and magnitude of exposures most representative of current and potential future site conditions.

The advantages of intrinsic remediation include: (1) contaminants are transformed to innocuous byproducts (e.g., carbon dioxide and water), not just transferred to another phase or location within the environment; (2) current pump-and-treat technologies are energy intensive and generally not as effective in reducing residual contamination; (3) the process is nonintrusive and allows continuing use of the land during remediation; (4) current engineered remedial technologies may pose a greater risk to potential receptors than intrinsic remediation because contaminants may be transferred into the atmosphere during remediation activities; and (5) intrinsic remediation is far less costly than conventional, engineered remedial technologies. The main limitation of intrinsic remediation is that it is a long-term solution which requires regular monitoring to confirm its progress.

To estimate the impact of natural biodegradation on the fate and transport of BTEX compounds in ground water at a site, two important lines of evidence must be demonstrated (Wiedemeier et al., in progress). The first is a documented loss of contaminants at the field scale. Dissolved-phase concentrations of biologically-recalcitrant tracers found in most fuel contamination are used in conjunction with aquifer hydrogeologic parameters such as ground water seepage velocity and dilution to demonstrate that a reduction in the total contaminant mass is occurring at the site. The second line of evidence involves the use of chemical analytical data in mass balance calculations to show that a decrease in contaminant and electron acceptor (e.g., oxygen, nitrate, sulfate) concentrations can be correlated to increases in metabolic fuel degradation byproduct concentrations (e.g., carbon dioxide, methane, ferrous iron). With this site-specific information, the Bioplume II computer model can be used to simulate the transport of dissolved-phase BTEX compounds under the influence of electron acceptor-limited biodegradation.

The Bioplume II model will be used to assess the influence of key electron acceptors on the fate and transport of BTEX compounds. The Bioplume II model is based upon the US Geological Survey (USGS) two-dimensional (2-D) solute transport model MOC, which has been modified to include a biodegradation component that is activated by a superimposed plume of dissolved oxygen. However, as part of this demonstration project, the biodegradation of fuel contamination will be activated by a superimposed plume of both oxygen and nitrate. Work completed as part of the Natural Attenuation

(Intrinsic Remediation) demonstration program, also sponsored by AFCEE, suggests that these compounds are the primary electron donors at a fuel site based on both thermodynamic and kinetic considerations. Use of both oxygen and nitrate in the Bioplume II model should provide a better estimate of the effectiveness of natural attenuation processes at the site at minimizing contaminant migration and reducing contaminant mass and toxicity. Use of both primary electron acceptors should also provide a better estimate of response time. Use of oxygen as the only electron acceptor can seriously underestimate the effects of natural degradation processes. The impact of including both in the Bioplume II model for this site may be a reduction in the source removal activities and time required to achieve site-specific remediation goals.

Bioplume II solves the USGS 2-D solute equation twice, once for hydrocarbon concentrations in the ground water and once for the electron acceptor plume. The two plumes are then combined using superposition at every particle move to simulate biological reactions between fuel products and the electron acceptors. Using even the most realistic worst-case data, Bioplume II generally predicts very limited migration of BTEX plumes due to natural attenuation processes. Bioplume II has been used to successfully demonstrate the effectiveness of intrinsic remediation at several sites (e.g., Wilson et al., 1986; Chiang et al., 1989; Rifai et al., 1988; Malone et al., 1993; Wiedemeier et al., 1993).

The risk-based approach to remediation is aimed at providing scientific evidence in support of the positive effects of intrinsic remediation and other innovative source removal technologies. The type and magnitude of these effects will be factored into the development of a final remedial alternative for the site. It is likely that intrinsic remediation alone will be insufficient at many fuel hydrocarbon-contaminated sites to reduce or eliminate contaminant migration and receptor risks. Other innovative source removal technologies, such as bioventing, will be included in the fate and transport calculations, risk analysis, and remedial design as necessary to ensure that the final remedial alternative will protect current and future receptors from adverse exposures to any site-related contamination (e.g., soil gas, soil, ground water, and surface water). Section 5 provides more detail on how quantitative models such as Bioplume II will be used to assess how well various remedial technologies eliminate or reduce contaminant migration and receptor risks.

3.3 OTHER QUANTITATIVE FATE AND TRANSPORT MODELS

The Summers model can be used to evaluate the potential impact of contaminated soil on ground water quality via downward precipitation infiltration (EPA, 1989a). This model may be useful to determine the potential for cross-media contamination, which may act as a continuing source of ground water contamination. The Summers model assumes that a percentage of rainfall at the site will infiltrate and desorb contaminants from the soil based on equilibrium partitioning between soil and liquid phases. Application of a fuel/water partitioning model such as that developed by Bruce et al. (1991) may also be required to provide a conservative estimate of how free-phase JP-4 dissolves into ground water.

Soil gas concentrations should not be directly used to assess potential air impacts due to VOCs diffusing upward through the vadose zone into the atmosphere or accumulating in buildings. ES will use flux isolation chambers to collect air samples

from the ground surface at several locations throughout the area. These actual flux samples taken over areas of known soil contamination will be used to estimate "worst-case" concentrations of VOCs entering the atmosphere and potentially entering occupied buildings via diffusion. Preferential soil gas migration routes (e.g., utilities) will also be considered, as necessary. Additional details on soil flux methods are included in Section 4. Several air diffusion and dispersion models recommended by the EPA (1992c) are available to determine air concentration levels in the atmosphere at several exposure points and accumulating in buildings. Actual flux concentrations will be coupled with a distance-related attenuation/dispersion equation to estimate the concentration in the air that a receptor may reasonably be expected to inhale. To estimate VOC concentrations in the atmosphere due to molecular diffusion through contaminated soil, this flux rate will be incorporated into a simple virtual upwind point-source dispersion equation recommended by the EPA to characterize potential air quality impacts (EPA, 1981 and 1992c).

To demonstrate that soil and ground water concentrations do not present a threat to individuals that may work or reside within buildings constructed on or adjacent to Site ST14, it may be necessary to use a simple diffusion/intrusion model to estimate the average annual VOC concentration that could accumulate in buildings due to upward contaminant flux from soil and ground water. The results of the flux monitoring described previously are then used as the input parameters for this model, which minimizes the effects of dispersion under atmospheric conditions by containing the flux within a structure. All of these models have been used successfully at many sites to quantitatively estimate the fate, transport, and impact of soil and ground water contamination on air quality.

Potential cross-media contamination effects on surface water bodies, such as Farmers Branch or the Trinity River, may also have to be considered in quantitative fate and transport analyses. If ground water fate and transport calculations indicate that a surface water body may be subject to ground water inflow, a simple mixing equation or a more complex chemical equilibrium model such as WATEQ4F, which was developed by the USGS, may be used to assess the chemical effects of ground water recharge. The simple mixing equation accounts for the effects of surface water flow on final contaminant concentration. WATEQ4F models the thermodynamic speciation of chemical species in solution once two source natural waters are mixed. As noted earlier, however, it is possible that natural attenuation mechanisms at the site may prohibit significant contamination from reaching surface water.

SECTION 4

PROPOSED SITE CHARACTERIZATION ACTIVITIES

To facilitate development and implementation of a risk-based remedial action for Site ST14, additional site-specific environmental media data will be collected. Soil gas, soil, ground water, and surface water will be sampled to (1) delineate the nature and extent of contamination, (2) support fate and transport analyses, (3) develop appropriate exposure point concentrations to compare to final remediation goals, and (4) evaluate and design an appropriate remedial alternative for the site. A sufficient number of samples from background and contaminated areas will be collected and analyzed for individual and indicator compounds to accurately assess the risk to human health and the environment posed by the site and to demonstrate the attainment of final cleanup levels.

Non-compound-specific analytical procedures (e.g., TRPH) will be used as screening methods to aid in the determination of the lateral and vertical extent and volume of contaminated media at Site ST14. These non-compound-specific analyses will be supplemented with compound-specific analyses. Development of a risk-based remedial alternative for Site ST14 will require an analysis of the potential chemical-specific threats posed to human health and the environment by individual compounds. Therefore, analytical data collected for the site will include a determination of the presence and concentration of individual chemicals.

4.1 GENERAL DATA NEEDS

Several data needs were identified as a result of developing the CSM for Site ST14 and assessing the input requirements for the quantitative fate and transport models. These data are necessary to prepare an EE/CA in support of a risk-based remedial action for Site ST14. Additional soil gas, soil, ground water, and surface water sampling will be performed. New ground water monitoring wells will be installed. Aquifer testing and limited source removal technology feasibility analyses will also be completed. Any additional existing information not incorporated into this TSTD/work plan will also be reviewed and used to the extent practicable to evaluate and design an appropriate remedial alternative for Site ST14 which eliminates or abates risks to human health and the environment to the maximum extent practicable. The data listed below will be determined during the field work phase of the risk-based approach to remediation.

Soil gas measurements will be used to determine the following site characteristics:

- Air-filled porosity of the first 2 feet of soils;

- Estimated flux rate of VOCs to the surface, if any;
- Efficiency of ongoing bioventing test in reducing soil gas BTEX;
- Soil gas oxygen concentrations by depth (current and before bioventing tests);
- Soil gas carbon dioxide concentrations by depth (current and before bioventing tests); and
- Concentrations of TVH, the BTEX compounds, naphthalene, and chlorobenzene by depth (current and before bioventing tests).

Characteristics of surficial soil, defined as the top 2 feet of soil at the site, to be determined through soil sampling and analysis include:

- Estimated effective porosity and air permeability;
- Total organic carbon (TOC) content and pH;
- Nature and extent of any surficial soil contamination; and
- Concentrations of TRPH and the BTEX compounds, and screening for chlorobenzene and naphthalene.

Both vadose zone (unsaturated) and phreatic zone (saturated) soil characteristics to be determined include:

- Detailed stratigraphic analysis of subsurface media;
- Air-filled and/or effective porosity;
- Estimated moisture content (unsaturated only);
- TOC content and pH;
- Total phosphorus and total Kjeldahl nitrogen concentrations by depth (current and before bioventing tests);
- Concentrations of TRPH and the BTEX compounds, and screening for chlorobenzene and naphthalene by depth (current and before bioventing tests);
- Estimated vertical extent of free product smear zone;
- Radius of oxygen influence of existing bioventing pilot system; and
- Estimation of fuel biodegradation rates within the bioventing radius of influence.

Physical hydrogeologic characteristics to be determined include:

- Depth from measurement datum to the ground water surface;
- Depth from measurement datum to the base of the shallow saturated zone (i.e., the top of the Goodland Formation) where feasible;
- Location of potential ground water recharge and discharge areas (including an assessment of the effectiveness of the french drain system and the effect of other hydrologic features);
- Hydraulic conductivity through slug tests; and

- Dispersivity (estimated).

Chemical hydrogeologic characteristics to be determined include:

- Determination of extent and thickness of free product, if any;
- Dissolved oxygen, sulfate, and nitrate/nitrite concentrations;
- Dissolved carbon dioxide, total alkalinity as carbonate and bicarbonate, and methane concentrations;
- Concentrations of each of the BTEX compounds and screening for chlorobenzene and naphthalene;
- Temperature;
- Specific conductance;
- TOC content and pH; and
- Chemical analysis of free product, if any, to determine mass fraction BTEX and PAH compounds.

Surface water physical and chemical characteristics to be determined include:

- Estimated flow rate at point of ground water inflow, if any;
- Hardness, pH, TOC content, and total suspended sediments (TSS); and
- Dissolved and total concentrations of the BTEX compounds and screening for naphthalene and chlorobenzene at three discrete locations (upgradient of, at, and downgradient of the potential point of discharge from the oil/water separator).

Table 4.1 lists the chemical analytical protocol for each of the environmental media to be sampled in support of a risk-based remedial design for Site ST14. This table also presents the detection limits required to support quantitative fate and transport analyses and calculation of exposure-point concentrations to compare to final remediation goals. Additional site-specific data necessary to support preparation of the EE/CA include (1) general climatic data, including prevailing wind speed and direction, average precipitation (as snow and rain), and temperature range; (2) relevant characteristics of Farmers Branch and the Trinity River, including ecological characteristics, seasonal flow rates, regulatory status, and designated uses; (3) existing and proposed land use plans for portions of Carswell AFB, including Site ST14 and downgradient environs; (4) presence or suspected presence of sensitive subpopulations such as the base day-care center, threatened or endangered species, or special-concern habitats; (4) ground water well locations and use information for areas likely to be affected by ground water migration; and (5) additional site-specific data necessary to justify site-specific land-use and exposure assumptions.

4.2 SAMPLING STRATEGY

The existing bioventing pilot system at Site ST14A, which consists of one bioventing well and 3 monitoring points, will be turned off at least 14 days before initiation of field work described herein to ensure data are representative of passive (at equilibrium) conditions at the site. Field investigation efforts will be completed in the

TABLE 4.1
SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Soil Gas

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Carbon dioxide content	Direct reading meter	0.2%	F	A	To determine carbon dioxide gradient with depth and to infer biological degradation of fuel- related compounds.
Oxygen content	Direct reading meter	0.2%	F	A	To determine oxygen gradient with depth, the presence or absence of aerobic degradation processes, and/or the effect of engineered systems on increasing oxygen content in soil.
Fuel hydrocarbon vapor content	Total combustible hydrocarbon meter	1 ppmv	F	A	A field screening method to determine extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.
Benzene	EPA TO-3	0.01 µg/L	L	B	Quantitative analysis to determine the nature and extent of soil contamination, the potential for adverse air quality effects, the need for source removal, and the effect of source removal techniques on specific compounds.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Soil Gas				
Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification* Data Use
Toluene	EPA TO-3	0.01 µg/L	L	B Same as Benzene
Ethylbenzene	EPA TO-3	0.01 µg/L	L	B Same as Benzene
Xylene	EPA TO-3	0.05 µg/L	L	B Same as Benzene
TVH	EPA TO-3	0.1 ppmv	L	B Non-compound-specific analysis to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques at reducing fuel- related contamination.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Soil

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Total combustible hydrocarbons	Direct reading meter	low reading	L	A	A field screening method to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.
Benzene	GC Method SW8020	10 µg/kg	L	B	Quantitative analysis to determine the nature and extent of soil contamination, the mass of contaminant present, the degree of weathering, the need for source removal, and the effect of source removal techniques on specific compounds.
Toluene	GC Method SW8020	10 µg/kg	L	B	Same as Benzene
Ethylbenzene	GC Method SW8020	10 µg/kg	L	B	Same as Benzene
Xylene	GC Method SW8020	30 µg/kg	L	B	Same as Benzene
Trimethylbenzene isomers	GC Method SW8020	10 µg/kg	L	B	Tracers to aid data evaluation on soil contamination and potential impact to ground water.
pH	E150.1	0.2	L	C	Aerobic and anaerobic processes are pH-sensitive.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Soil

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
TRPH	Modified 8015		L	C	A non-compound-specific method to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.
TOC	Modified SW9060		L	D	Relatively high amounts of TOC may be indicative of a reducing environment and may indicate the need for analysis of electron acceptors associated with that environment; the rate of migration of fuel-related compounds in ground water is dependent upon the amount of TOC in phreatic soils; the rate of release of fuel-related compounds from the source to ground water is in part dependent on the amount of TOC in the unsaturated soil.
Chlorobenzene	GC/MS Method SW8240	10 µg/kg	L	D	Compound-specific to determine nature and extent of such contamination and the potential for source contamination.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Soil

Analysis	Method	Required		Field or Laboratory	Analysis Classification *	Data Use
		Detection Limit				
Napthalene	GC/MS Method SW8720	330 µg/kg	L	D		Quantitative analysis to determine the nature and extent of such contamination, the potential source mass present, the degree of weathering, and the need for source removal.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Ground Water

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Depth to water	Water probe	0.01 ft	F	A	Hydrogeological characterization; well development.
Thickness of product	Oil/water probe	0.01 ft	F	A	To determine extent of potential continuing source to ground water, the mass of source contamination, and the need for source removal.
Temperature	E170.1	0.2°C	F	A	Well development.
DO content	Downhole DO probe	0.2 mg/L	F	A	Data input to Bioplume II model; depleted levels generally indicate inhibited aerobic degradation and potential presence of anaerobic degradation processes; concentrations less than 1 mg/L correlate well to elevated dissolved- phase BTEX contamination.
pH	E150.1/direct reading	0.2	F	A	Aerobic and anaerobic processes are pH-sensitive.
Benzene	GC Method SW8020	1 µg/L	L	B	Primary compound-specific analytes used to estimate and monitor intrinsic remediation; used to determine nature and extent of contamination; the degree of weathering; and used to establish

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Ground Water					
Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Toluene	GC Method SW8020	1 µg/L	L	B	Same as Benzene
Ethylbenzene	GC Method SW8020	1 µg/L	L	B	Same as Benzene
Xylenes	GC Method SW8020	3 µg/L	L	B	Same as Benzene
Trimethylbenzene isomers	GC Method SW8020	--	L	B	To monitor and correct for plume dilution effects in Bioplume II model setup.
Chlorobenzene	GC/MS Method SW8240	1 µg/L	L	C	Compound-specific to determine nature and extent of such contamination.
Napthalene	GC/MS Method SW8310	5 µg/L	L	C	To determine nature and extent of such contamination; the degree of weathering; and to establish and demonstrate compliance with site- specific remediation goals.
Alkalinity	Colorimetric E310.2	--	F/L	C	To verify that ground water samples are obtained from same system and to measure the buffering capacity of the aquifer.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Ground Water					
Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Nitrate	Colorimetric E353.2	2 mg/L	F/L	C	Secondary substrate (electron acceptor) for microbial respiration if oxygen is depleted; data input to Bioplume II model.
Sulfate	HACH SulfaVer 4	--	F	C	Potential substrate for anaerobic microbial respiration; will be used semi-quantitatively when evaluating intrinsic remediation.
Carbon dioxide	HACH	--	F	C	Carbon dioxide can be an electron acceptor for anaerobic microbial respiration; the presence of free carbon dioxide dissolved in ground water is unlikely given natural buffering capacities. If detected, concentrations will be compared to background levels to determine if they are elevated, which could suggest aerobic degradation.
Total hydrocarbons	GC Method SW8015	--	L	C	To estimate the extent of contamination and to monitor the reduction in fuel-related contamination due to natural attenuation.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Ground Water

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Ferrous (Fe^{2+})	HACH 25140-25	0.06 mg/L	F	C	May indicate an anaerobic degradation process as a result of depletion of other electron acceptors such as oxygen and nitrate.
Aquifer slug test	See Work Plan	--	F	D	Hydrogeological characterization.
Tracer test	See Work Plan	--	F	D	Hydrogeological characterization.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Surface Water

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
pH	direct reading	--	F	A	Fate and transport of BTEX compounds in surface water is pH-sensitive; required remediation goals are pH-dependent.
Benzene	GC Method SW8020	1 µg/L	L	A	To determine nature and extent of contamination, potential for cross-media contamination, and compliance with remediation goals for surface water.
Toluene	GC Method SW8020	1 µg/L	L	A	Same as Benzene
Ethylbenzene	GC Method SW8020	1 µg/L	L	A	Same as Benzene
Xylenes	GC Method SW8020	3 µg/L	L	A	Same as Benzene
Trimethylbenzene isomers	GC Method SW8020	--	L	A	Possible tracers to monitor the reduction in chemical contamination due to dilution.
TOC	Modified SW9060	--	L	A	Fate and transport of BTEX and other fuel-related compounds influenced by presence of TOC; required remediation goals are also dependent upon TOC.

TABLE 4.1 (Continued)

SOIL GAS, SOIL, AND WATER SAMPLING PROTOCOL
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Matrix: Surface Water

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Chlorobenzene	SW8240	1 µg/L	L	B	Compound-specific to determine nature and extent of contamination and to demonstrate compliance with remediation goals.
Napthalene	SW8310	5 µg/L	L	B	To determine nature and extent of such contamination and to demonstrate compliance with remediation goals.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

following sequence: (1) soil gas survey, (2) soil gas sampling for compound-specific analysis, (3) soil gas flux sampling, (4) drilling, soil sampling, and well installation in least contaminated area, (5) drilling, soil sampling, and well installation in most contaminated areas, (6) well development, (7) collection of physical ground water data from least to most contaminated areas, excluding slug and tracer tests, (8) collection of ground water samples from least to most contaminated areas for chemical analyses, (9) slug and tracer tests, and (10) surface water samples. Several of these activities can be conducted concurrently at the discretion of the ES site manager to expedite the field work phase of this project. However, care must be taken to minimize cross-contamination and other medium-specific effects that could complicate data evaluation. Appendix A to this TSTD/work plan is the detailed site-specific sampling and analysis plan. Specific procedures and protocols for each type of field activity to be completed at Site ST14, including quality assurance requirements, are presented in this appendix.

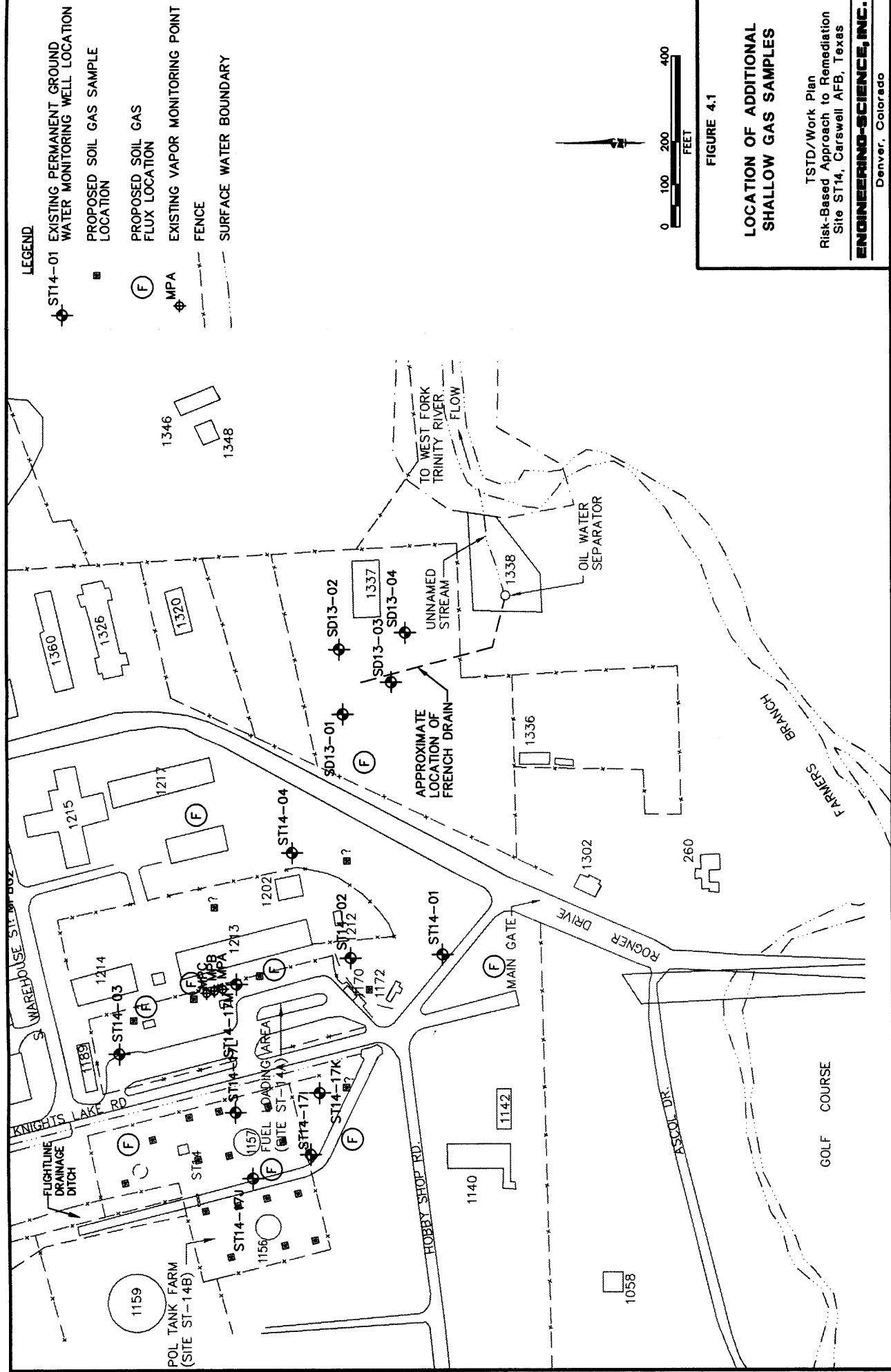
4.2.1 Soil Gas Sampling

Shallow soil gas probes will be used to better define the areal extent of soil gas and soil contamination and the potential for lateral and upward diffusion of soil contamination in the soil-pore vapors at the site. The shallow soil gas probe will be pushed to a depth of approximately 2 to 3 feet bgs, soil gas will be withdrawn, and analyzed for concentrations of the BTEX compounds and screened for chlorobenzene. The data collected using the shallow soil gas probes will be used to supplement soil gas measurements from permanent vapor extraction points installed at Site ST14 as part of the bioventing pilot test and the soil gas surveys completed at Site ST14B.

It is anticipated that three to four temporary locations will be sampled just to the east and west of Building 1213 at Site ST14A. These soil gas locations are indicated on Figure 4.1. If these initial soil gas sample locations suggest detectable concentrations of any of the COCs based on field TVH screening, two additional sample locations downgradient of Site ST14A will also be sampled. Shallow soil gas samples will be analyzed as prescribed in Table 4.1. Soil gas samples will also be collected from the three existing vapor monitoring points (MPA, MPB, MPC) at the shallow depths (approximately 4 feet bgs) associated with the ongoing bioventing pilot study.

Additionally, 15 to 18 temporary locations will be sampled on Site ST14B to confirm the probable areal extent of soil gas and soil contamination prior to initiating intrusive investigation techniques such as drilling. These locations are also identified on Figure 4.1. All soil gas samples will be field screened for TVH. The results of this non-compound-specific survey will be used to identify the four to five locations that indicate the highest TVH measurements. These temporary locations will be re-sampled and quantitatively analyzed for specific compounds as prescribed in Table 4.1. This two-phase soil gas survey is necessary to supplement existing and proposed non-compound-specific data with compound-specific results. TVH measurements are not sufficient to establish final remediation goals and design a remedial action for this site.

Flux sampling will also be conducted at several of the soil gas probe locations, as shown in Figure 4.1. Three of these locations are in areas of known subsurface soil contamination along the eastern boundary of Site ST14A. One is in the suspected source area of Site ST14B. Four additional sampling locations have been selected in



grassy areas several hundred feet downgradient of potential source areas. The purpose of flux sampling in these areas will be to more accurately estimate the upward diffusion of VOCs from the soil into the atmosphere or potentially into buildings downgradient of the source area. One flux sample will be taken from a known background area, located north of ST14. The exact location of this background flux sample will be determined following the TVH soil gas survey.

Soil gas and flux sampling will be conducted by qualified ES scientists and technicians trained in the conduct of soil gas shallow probe sampling and soil flux measurement. In addition, sampling personnel will have thoroughly reviewed this TSTD/work plan, including Appendix A, prior to sample acquisition and will have a copy of both available onsite for reference.

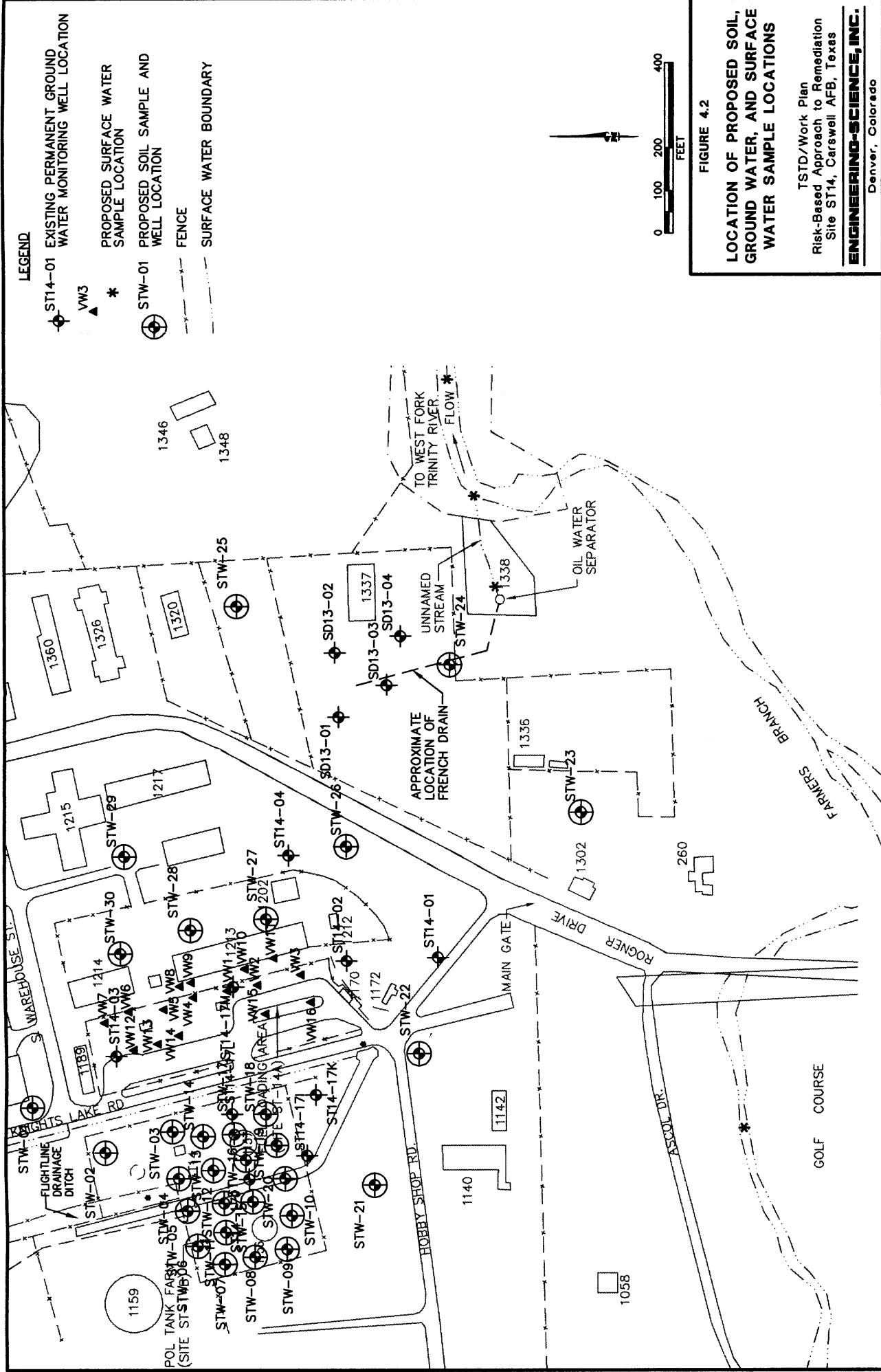
4.2.2 Soil Sampling

Soil drilling and sampling will also be necessary to characterize the nature and extent of vadose and phreatic zone soil contamination at and immediately downgradient of Site ST14. Continuous soil cores will be taken at 30 locations identified on Figure 4.2. Permanent bioventing wells or ground water monitoring wells will be installed at each of these soil boring locations. Soil cores will be carefully evaluated to determine the stratigraphy of the sample location and the vertical depth of any measurable or visible contamination, sampled for laboratory analyses, and then composited for headspace readings. A maximum of three soil samples will be taken per soil core. Samples will be taken in 2-foot intervals for analytical analyses. Samples will be taken from the first 2 feet bgs if there is indication of surface contamination, and from the soil interval beginning at the capillary fringe and the interval extending below the ground water surface. The number of required samples taken will depend on the extent of apparent soil contamination (as indicated by olfactory, visual, or volatile organic analyzer inspection). Soil borings which exhibit an interval of soil contamination exceeding 2 feet above the water table will be converted to 4-inch-diameter bioventing wells. All others will be converted to 2-inch-diameter permanent ground water monitoring wells. Table 4.1 identifies both screening and analytical requirements for collected soil samples. The new soil sampling locations were selected to provide additional information about site stratigraphy, background concentrations, the extent of probable source contamination, and the extent of the contamination downgradient of Site ST14. The locations have been selected to support implementation of source removal activities, as necessary.

Soil sampling will be conducted by qualified ES scientists and technicians trained in the conduct of soil drilling, sampling, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this TSTD/work plan, including Appendix A, prior to sample acquisition and have a copy of both available onsite for reference.

4.2.3 Ground Water Sampling

New ground water monitoring wells will be constructed at each soil boring location not completed as bioventing wells to further delineate the nature and extent of ground water contamination at the site. Additionally, a maximum of 11 existing ground water monitoring wells and 3 partially completed bioventing wells will be resampled using a



peristaltic pump to further delineate probable source areas of contamination, the areal extent of the dissolved-phase plume, and other hydrogeologic characteristics. Other ground water monitoring wells and bioventing wells will be used to characterize physical rather than chemical characteristics, such as depth to the ground water surface.

Emphasis will also be placed on defining the estimated extent of any remaining free fuel product that may act as a continuing source of soil gas and ground water contamination. Free product can be physically identified using an oil/water interface probe. Moreover, ground water samples showing a benzene concentration equal to or in excess of 178 mg/L (10 percent of its maximum solubility in water) will be operationally defined as potential fringe areas to oily-phase contamination (or underlying significant residual soil contamination).

Figure 4.2 identifies the locations of the new wells that may be completed as permanent ground water monitoring wells, and Table 4.2 identifies the existing ground water monitoring wells and bioventing wells that will be sampled as part of this characterization effort. Note that not all existing ground water and bioventing wells points will be sampled for chemical analyses at this time. Further, Law Environmental Government Services is in the process of installing several new ground water wells that may be used a part of this investigation. Ground water samples taken as part of this field effort will be analyzed as prescribed in Table 4.1. Data from previous investigations will be incorporated into the final analysis to the extent practicable to avoid unnecessary duplication of field results. At least one free product sample will be recovered, if possible, and subjected to a full chemical constituent analysis to determine how free fuel constituents will partition into the ground water and contribute to the dissolved-phase plume.

4.2.4 Aquifer Testing

Aquifer testing will be completed using ground water monitoring wells STW-01, STW-05, STW-14, STW-20, STW-23, STW-26, STW-29, ST14-01, and SD13-02. The objective of these tests is to provide further information on the hydrogeologic conditions specific to Site ST14 and the areas suspected to be immediately downgradient of probable source areas. These field tests are necessary to support quantitative fate and transport analyses using the Bioplume II model. A conservative tracer test also will be conducted between ground water monitoring wells STW-24 and SD13-03 and the french drain system to estimate the impact of this subsurface structure on ground water flow. These two tracer tests will be conducted to measure the direction and velocity of ground water flow, particularly in the immediate vicinity of the french drain system. A conservative tracer that travels with the same velocity and in the same direction as ground water will be used in this test. Either an ionic tracer such as lithium bromide or a dye trace such as Rhodamine WT will be used at Site ST14 between monitoring wells STW-24 and SD13-03 and the french drain system. If lithium bromide is used as the tracer, mobility will be tracked using a conductivity probe. Rhodamine WT is a fluorescent dye that is inexpensive, commonly used in tracer studies, and is easily detected. Figure 4.2 identifies the ground water monitoring wells which will be used to characterize aquifer parameters and the effect of the french drain system.

TABLE 4.2
SITE-SPECIFIC SAMPLING STRATEGY
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Sample Location	Analysis Classification*	Sample Location	Analysis Classification*
Soil gas (up to 22 total)	A	Soil STW-28	A, B, C, D
Soil gas (9 total)	B	Soil STW-29	A, B
Soil flux (8 total)	A, B	Soil STW-30	A, B
Soil STW-01	A, B, C, D	Water STW-01	A, B, C, D ^{a/}
Soil STW-02	A, B	Water STW-02	A, B, C ^{c/}
Soil STW-03	A, B	Water STW-03	A, B
Soil STW-04	A, B	Water STW-04	A, B, C
Soil STW-05	A, B, C, D	Water STW-05	A, B, D ^{a/}
Soil STW-06	A, B	Water STW-06	A, B, C ^{c/}
Soil STW-07	A, B	Water STW-07	A, B
Soil STW-08	A, B, C, D	Water STW-08	A
Soil STW-09	A, B	Water STW-09	A, B
Soil STW-10	A, B	Water STW-10	A, B, C
Soil STW-11	A, B	Water STW-11	A, B
Soil STW-12	A, B, C, D		
Soil STW-13	A, B	Water STW-12	A, B, C
Soil STW-14	A, B	Water STW-13	A
Soil STW-15	A, B, C, D	Water STW-14	A, B, D ^{a/}
Soil STW-16	A, B	Water STW-15	A, B, C ^{c/}
Soil STW-17	A, B, C, D	Water STW-16	A, B
Soil STW-18	A, B	Water STW-17	A
Soil STW-19	A, B	Water STW-18	A, B, C
Soil STW-20	A, B, C, D	Water STW-19	A, B
Soil STW-21	A, B, C, D	Water STW-20	A, B, C, D ^{a/}
Soil STW-22	A, B, C, D	Water STW-21	A, B
Soil STW-23	A, B, C, D	Water STW-22	A, B, C
Soil STW-24	A, B	Water STW-23	A, B, C, D ^{a/}
Soil STW-25	A, B	Water STW-24	A, B, C, D ^{b/}
Soil STW-26	A, B, C, D	Water STW-25	A, B, C ^{c/}
Soil STW-27	A, B	Water STW-26	A, B, C, D ^{a/}

TABLE 4.2 (Continued)
SITE-SPECIFIC SAMPLING STRATEGY
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Sample Location	Analysis Classification*	Sample Location	Analysis Classification*
Water STW-27	A, B, C		
Water STW-28	A, B		
Water STW-29	A, B, D ^{a/}		
Water STW-30	A, B, C		
Water ST14-17I	A, B		
Water ST14-17J	A, B		
Water ST14-17K	A, B		
Water ST14-17L	A, B, C ^{c/}		
Water ST14-17M	A, B, C		
Water ST14-01	A, B, D ^{a/}		
Water ST14-02	A, B, C ^{c/}		
Water ST14-03	A, B		
Water ST14-04	A, B		
Water SD13-02	A, B, D ^{a/}		
Water SD13-03	A, B, C, D ^{b/}		
Surface Water (up to 6 total)	A, B		

Note: 3 existing bioventing wells will be sampled for ground water quality parameters.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited. Table 4.1 describes analysis classification requirements by medium.

a/ Slug test only

b/ Tracer test only

c/ Except chlorobenzene and naphthalene

4.2.5 Surface Water Sampling

Surface water grab samples will be taken at six discrete locations up- and downgradient of Site ST14: (1) at the Flightline Drainage Ditch, (2) at the outfall of the Flightline Drainage Ditch, if possible, (3) at the outfall of the oil/water separator located south of the new communications building (Building 1337) and immediately south of the fenced civil engineering storage yard, (4) within Farmers Branch adjacent to the oil/water outfall, which is located approximately 1,000 feet southeast of Site ST14A, (5) within Farmers Branch upgradient of the oil/water separator outfall, and (6) at the confluence of Farmers Branch and the West Fork of the Trinity River, located approximately 1,600 feet east of Site ST14. Figure 4.2 identifies the approximate locations of proposed surface water samples. Every effort will be made to collect surface water samples from the Flightline Drainage Ditch. Unlike the Unnamed Stream, however, this hydrologic feature probably only contains sufficient water to sample immediately following a precipitation event. Other surface water samples should not be collected after a high precipitation event to prevent possible dilution effects.

4.3 SOURCE REMOVAL FEASIBILITY TESTING

It is anticipated that some level of soil or ground water remediation may be required to reduce the source of BTEX contamination migrating away from Site ST14 and to reduce potential exposures to these compounds. Recent soil sampling at 26 locations at Site ST14A revealed an average total BTEX concentration of 26 mg/kg exists in the 7- to 11-foot bgs interval (ES, 1993). An average benzene concentration of 3.6 mg/kg was detected in this interval. Because this soil contamination may represent a significant source of future ground water and soil gas contamination, some level of remediation may be warranted. Small amounts of free product are also present in the source area capillary fringe, although levels appear to have significantly decreased over the past 3 years (see section 2). No compound-specific data for Site ST14B has been collected.

In addition to intrinsic remediation, three active remediation methods will be considered during the EE/CA process. The three technologies are *in situ* bioventing of soils, limited free product recovery, and air sparging to promote VOC removal from the ground water and to add DO to the aquifer. Additional data is required to complete an accurate evaluation of these source removal methods.

4.3.1 Initial Bioventing Results

Bioventing is an innovative technology which uses low rates of air injection to supply oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons. The Air Force has successfully used bioventing for remediation of several JP-4 spill sites (Downey et al., 1993). A bioventing pilot test was initiated at Site ST14 in May of 1993 to determine the feasibility of using this technology for reducing BTEX and total petroleum hydrocarbons in contaminated soils (ES, 1993). One air injection vent well (VW-1) and three vapor monitoring points were installed near monitoring well ST14-17M (Figure 2.2).

Test procedures outlined in the Air Force bioventing protocol document (Hinchee et al., 1992) were followed, and included an air permeability test, oxygen influence test and *in situ* respiration test. Results of the air permeability test indicated an average soil permeability of 61 darcys with a pressure influence extending at least 45 feet from the air injection well. Air flow through fine-grained soils 4 to 7 feet bgs was also observed, as was an increase in soil gas oxygen. Unfortunately, the water table was only 8.5 feet bgs during the test, and the oxygen influence in deeper soils could not be measured. As the water table drops during the summer and fall, the radius of oxygen influence in deeper, coarse-grained soils is expected to exceed 45 feet.

Initial soil gas measurements indicated fully depleted oxygen conditions in the soil were limiting the rate of biological fuel degradation. The biological uptake of oxygen by soil bacteria was measured at both the 4- and 7-foot depth interval by injecting air into vapor monitoring points and then measuring the uptake of oxygen by soil bacteria. Rapid uptake was observed at all points indicating a significant population of hydrocarbon degrading bacteria in the soil. Based on oxygen uptake rates, potential hydrocarbon degradation was estimated at 950 to 9,900 mg of fuel per kg of soil per year.

Based on the positive results of this test, ES completed a conceptual design of a full-scale bioventing system and constructed 16 bioventing wells in contaminated soil borings at Site ST14A (ES, 1993). Although these 16 vent wells do not completely cover the probable extent of soil contamination, the additional soil borings at Site ST14A proposed in this TSTD/work plan could be completed as bioventing wells and added to the current bioventing system design if they contain significant soil contamination.

The performance of the existing bioventing system will be analyzed during the upcoming fieldwork. If the ground water table has dropped, the radius of oxygen influence will be verified in the deep (> 10 feet bgs) vapor monitoring points. Soil gas will be analyzed to estimate the reduction in soil BTEX that has occurred during the first year of pilot testing.

4.3.2 Free Product Recovery

If analysis reveals that a significant BTEX source remains as free product, it is possible that additional product recovery will be required in the source area. To date, free product recovery has been limited to hand bailing of well ST14-17M by base personnel. Table 4.3 summarizes the quantities of free product that have been recovered on a weekly basis over the past 10 months. Current levels of recovery indicate that the free product may be too dispersed to recover without significant ground water pumping and aboveground separation. During future fieldwork, ES will carefully examine the 16 new bioventing wells (which are completed several feet into the ground water) and all other newly installed wells to determine if free product is still present near ST14-17J and extends beyond the well ST14-17M area.

4.3.3 Biosparging Test

Biosparging involves the injection of air into saturated soils with the purpose of increasing DO levels and removing a portion of the BTEX from the source area

TABLE 4.3
FREE PRODUCT THICKNESS MEASUREMENTS
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Date	Free Product Thickness (inches)
6/16/93	Trace
7/1/93	0.18
7/23/93	2.0
8/6/93	2.5
9/10/93	1.0
10/8/93	1.12
11/19/93	0.37
12/30/93	0.63
1/28/94	0.25
2/16/94	0.50
3/10/94	Trace
4/11/94	0.75

groundwater through volatilization. Biosparging is under consideration at this site because initial measurements indicate that less than 2 mg/L of DO is available throughout most of the source area.

A single sparging point will be established between VW-12 and ST14-03 to measure the potential upgradient and downgradient impact of air injection. The sparging point will be constructed of 1-inch, Schedule 80 PVC with a 2-foot screened interval placed at a depth of 14 to 16 feet bgs. An oilless, rotary-vane compressor will be used to inject air at an estimated 3 to 5 standard cubic feet per minute (scfm) into the shallow aquifer. The required injection pressures will be measured for various flow rates. Initial and daily DO readings will be made at VW-12 and ST14-03 to estimate the radius of oxygen influence from a single sparging point. Data from this test will be used in the event that a larger biosparging system is required to provide additional oxygen to the shallow aquifer to promote more rapid biodegradation of BTEX compounds.

SECTION 5

REMEDIAL OPTION EVALUATION AND EE/CA REPORT

Upon completion of the field work in support of the risk-based approach, a quantitative source and release analysis using sample partitioning models and Bioplume II will be completed to determine the fate and transport of fuel-hydrocarbon-contamination at the site and to estimate the effectiveness of intrinsic remediation. For example, the Bioplume II model will be used to investigate whether natural attenuation is occurring at the site, and if so, to what extent do these processes minimize contaminant migration. Based upon model predictions of contaminant concentration and distribution in various media through time, an exposure pathway assessment will be conducted. If the model predictions suggest that contamination may exist at or migrate to an exposure point, the exposure pathway will be considered complete. To identify the type and magnitude of remediation that may be required to protect human health and the environment, appropriate numerical remediation goals for each environmental media and COC will be identified. Data from the models used to determine whether an exposure pathway may be complete will also be used to estimate exposure point concentrations using the guidance developed by EPA (1992) concerning reasonable maximum exposure.

A qualitative screening of the various remedial technologies will be conducted to narrow the list to only those that are likely to address the principal threats posed by the site. These remedial technologies will then be combined as necessary to create a remedial alternative (e.g., alternative 1: bioventing, intrinsic remediation, long-term monitoring, and deed restriction recordation). An iterative, quantitative evaluation of the effectiveness of these final remedial alternatives in achieving these site-specific remediation goals will then be completed.

5.1 EE/CA OBJECTIVES

The objectives of this demonstration project and the EE/CA are to evaluate, select, design, and implement the remedial alternative that:

- Meets the cleanup goals for the site;
- Is permanent or at least achieves the highest degree of long-term effectiveness possible; and
- Is cost effective in that it achieves the best balance between long-term effectiveness and cost.

The EE/CA prepared as part of this demonstration project will satisfy the final report requirements of Section 335.553(b)(4) to demonstrate attainment under TNRCC Risk Reduction Standard No. 3. The EE/CA will contain complete information on all aspects of the final remedial alternative recommended for the site, including quantitative and other evaluation data, long-term monitoring requirements, and long-term land use restrictions.

5.2 MAJOR COMPONENTS OF THE EE/CA

The following sections briefly present the major components of an EE/CA. The EE/CA will contain detailed information on field and laboratory analytical results; quantitative source, release, fate, and transport analyses; exposure point concentration; toxicity data; identification of appropriate preliminary and final remediation goals; and the factors affecting and methods used to evaluate potential remedial alternatives for the site. The EE/CA will also recommend and present a design for the most appropriate remedial alternative for the site. Construction of required source removal systems will begin immediately following base and regulatory approval of the EE/CA.

5.2.1 Data Presentation

The EE/CA will be structured to clearly and concisely present the approach and results of each of the major steps completed to select, design, and implement an appropriate remedial alternative for the site which minimizes risks to human health and the environment to the extent practical. Figure 5.1 presents an example EE/CA outline that will guide the development of data and supporting text. The EE/CA will be structured to place emphasis on the results of field work, risk analysis, and remedial alternative evaluation. Detailed information on the methodology used in each of these steps will be contained in appendices to the EE/CA. This approach should streamline the final report to focus on the results of the evaluation. In this way, regulators and other decision-makers will not have excessive documentation to review to determine whether the recommended remedial alternative meets all the stated objectives of the project.

5.2.2 Data Evaluation and Modeling

Data from field work conducted in support of the risk-based demonstration project that will be used in quantitative analyses will be gathered and sorted by environmental medium. Any analytical data used in this demonstration project will be evaluated in terms of their quality. This data-useability review will include a review of the analytical methods, quantitation limits, and other factors important in determining the precision, accuracy, completeness, and representativeness of the final data set. The outcome of this data evaluation will be a data set appropriate to support quantitative fate and transport analyses and risk analysis. The data evaluation methods defined by EPA (1989b) in OSWER Directive 9285.7-01a *Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual* (EPA/540/1-89/002) and OSWER Directive 9285.7-09a *Guidance for Data Usability in Risk Assessment* (EPA, 1992a) will be used as appropriate. By using the analytical methods and quantitation limits defined in this TSTD/work plan (see Table 4.1), the data collected during the field work phase of this demonstration project are designed to satisfy the

FIGURE 5.1

EXAMPLE REPORT OUTLINE
TSTD/WORK PLAN
SITE ST14, CARSWELL AFB, TEXAS

Executive Summary

- 1.0 Introduction
 - 1.1 Purpose and Scope
 - 1.2 Site Background
 - 1.3 Report Organization
- 2.0 Site Description
 - 2.1 Physical Setting
 - 2.2 Nature and Extent of Contamination
 - 2.2.1 Previous Investigations
 - 2.2.2 Recent Data
 - 2.3 Indicator Analyte Data
 - 2.4 Discussion of Evidence of Intrinsic Remediation
- 3.0 Evaluation Methods and Criteria
 - 3.1 Remedial Action Objectives
 - 3.2 Potential Exposure Pathways for Human/Ecological Receptors
 - 3.3 Site-Specific Fate and Transport Models
 - 3.4 Site-Specific Cleanup Goals
 - 3.5 Review of Evaluation Criteria
 - 3.5.1 Protectiveness
 - 3.5.2 Implementability
 - 3.5.3 Cost
- 4.0 General Description of Potential Remedial Alternatives (Examples)
 - 4.1 Alternative 1: Intrinsic Remediation/Long-term Monitoring
 - 4.2 Alternative 2: Bioventing to Remove Soil Source(s)/Intrinsic Remediation/Long-Term Monitoring
 - 4.3 Alternative 3: Remove Free Product/Intrinsic Remediation/Long-Term Monitoring
 - 4.4 Alternative 4: Soil Vapor Extraction/Ground Water Pump and Treat
- 5.0 Comparative Analysis of Remedial Alternatives
 - 5.1 Protectiveness
 - 5.2 Implementability
 - 5.2.1 Technical
 - 5.2.2 Administrative
 - 5.3 Cost
 - 5.3.1 Capital Costs
 - 5.3.2 Operating Costs
 - 5.3.3 Present Worth Cost
- 6.0 Recommended Remedial Alternative
- 7.0 References

Appendix A: Data Evaluation for Risk Analysis

Appendix B: Development of Site-Specific Cleanup Goals

Appendix C: Quantitative Exposure Assessment Data (Model Simulations)

rigorous data requirements of quantitative risk analysis. Results of this data evaluation will be summarized in the EE/CA.

Data will be used as input parameters to the various quantitative models discussed in Section 3.2 and 3.3, as necessary, to explore potential exposure-pathways that may or will be completed at the site. Models which require a single-point concentration value (e.g., air dispersion) will use exposure-point concentrations developed using the EPA (1992b) *Supplemental Guidance to RAGS: Calculating the Concentration Term* (Publication 9285.7-081). This guidance is designed to assist in the development of an exposure concentration that represents the highest exposure that could reasonably be expected to occur for a given exposure pathway. This value is intended to account for both the uncertainty in environmental data and the variability in exposure parameters. This approach is consistent with that recommended in the TNRCC risk-reduction rule.

More complex models such as Bioplume II do not require single-point values. In these cases, unadjusted field data will be used to simulate the fate and transport of contamination in the ground water. If model predictions demonstrate that an exposure pathway involving ground water is not complete, it will be unnecessary to develop exposure concentrations to compare to appropriate cleanup goals. Conversely, if model predictions show that an exposure pathway involving ground water is or may be completed, data from model sensitivity runs at the point of exposure will be statistically evaluated to determine a single-point exposure concentration. The goal of this approach is to factor model uncertainty into the development of an exposure-point concentration that is most representative of the reasonable maximum exposure at the site. Again, EPA (1992b) guidance will be followed to develop exposure concentration values suitable for comparison to appropriate cleanup concentration goals.

5.2.3 Method of Risk Analysis

The method of risk analysis to be employed in this demonstration project is analogous to that used to evaluate long-term risks associated with various remedial alternatives (TNRCC, 1993). Quantitative and qualitative data on risks that may remain after implementation of a specific remedial technology will be used to evaluate and select a final remedial alternative for the site. The risk analysis method consists of three basic steps: (1) identifying site-specific exposure pathways that are either complete or not complete, (2) developing appropriate remedial concentration goals for COCs based on site-specific considerations, and (3) determining the type and magnitude of remedial action required to meet cleanup goals for the site. The risk analysis method thus encompasses the four basic components of a traditional risk assessment (i.e., data evaluation, exposure assessment, toxicity assessment, and risk characterization). The risk-based approach improves upon traditional approaches by using the tools of risk assessment to identify which remedial alternative achieves the best balance between risk reduction and cost. Figure 5.2 summarizes the risk analysis method.

5.2.3.1 Exposure Pathway Evaluation

As described in Section 3 of this TSTD/work plan, an exposure assessment identifies the potential human and ecological receptors that could come into contact with site-related contamination and the pathways through which these receptors might be

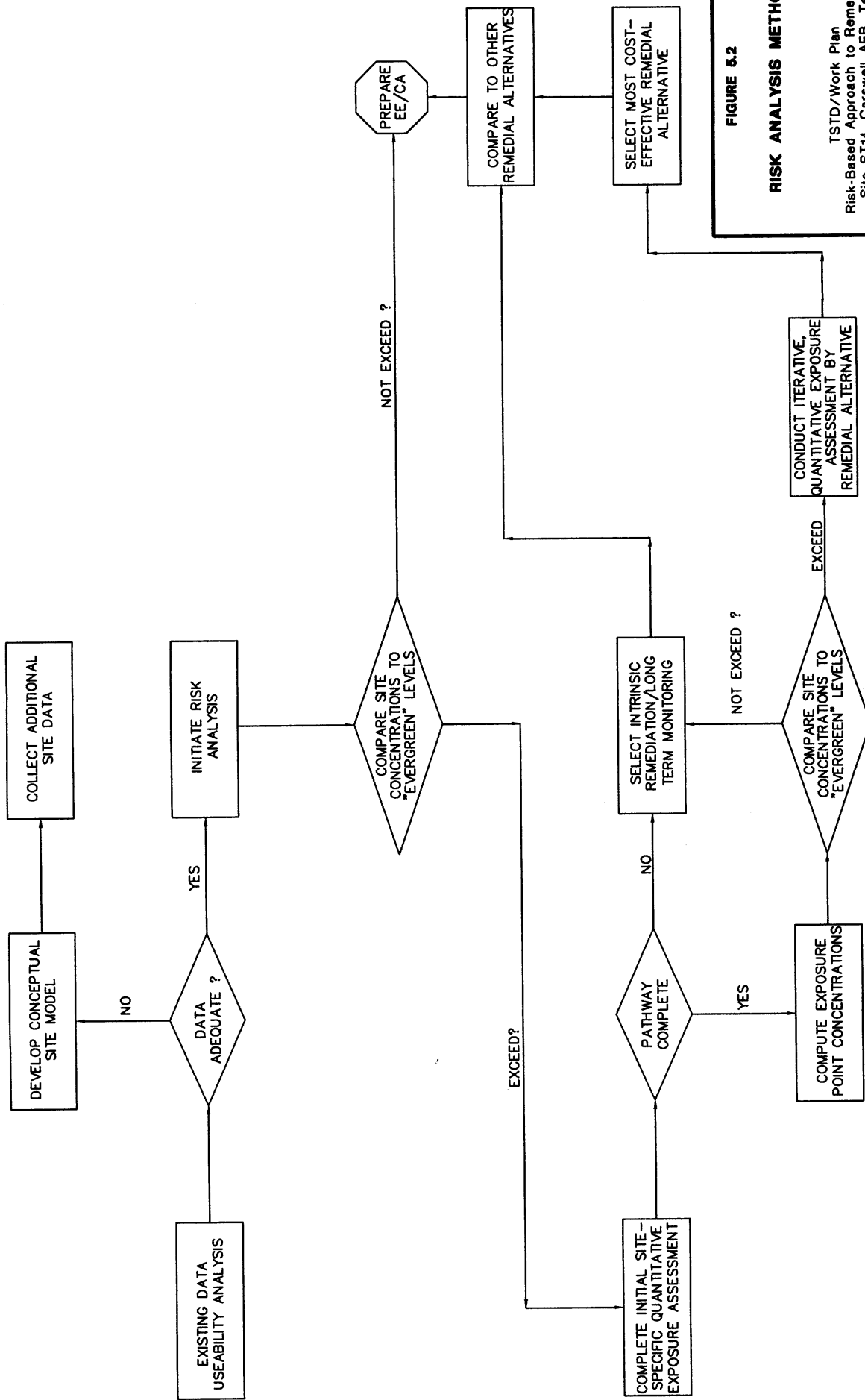


FIGURE 5.2

RISK ANALYSIS METHOD

TSTD/Work Plan
 Risk-Based Approach to Remediation
 Site ST14, Carswell AFB, Texas

ENGINEERING-SCIENCE, INC.
 Denver, Colorado

exposed. To have a completed pathway of exposure, there must be a source of contamination, a mechanism of release, a receptor, and a route through which the contamination could reach the receptor. The risk-based approach to remediation is designed to use quantitative field data and models to characterize both the existing nature and extent of contamination and what effect various remedial technologies such as intrinsic remediation will have on the fate and transport of contaminants through time. The CSM presented in Section 3 of this TSTD/work plan identifies potential source and release mechanisms, existing and potential future receptors, exposure points, and exposure routes that may be involved in current or future exposure scenarios for the site. This CSM was developed to ensure that adequate data are collected to support a quantitative evaluation of the potential for exposure pathway completion at the site and development of final site-specific remediation goals.

Field data and model simulations which account for the physical setting and characteristics of the site will be used to estimate whether any exposure pathway is completed and, if so, to quantify the COC concentrations at the point of exposure. The method of risk analysis to be used as part of this demonstration project hinges on achieving remediation goals for each environmental media.

If an exposure pathway is determined to be completed, the exposure assessment will be expanded to calculate exposure-point concentrations. As discussed in Section 5.2.2, field data and model simulation results will be statistically evaluated using EPA (1992b) guidance on how to calculate a single-point concentration level that represents the highest concentration to which a receptor could reasonably be exposed given site conditions (i.e., the reasonable maximum exposure). Using modeled data in the calculation of the exposure-point concentration is designed to account for the positive effects of natural attenuation processes that may be operating at the site.

5.2.3.2 Identifying Cleanup Goals

To evaluate, select, and design an appropriate remedial alternative for a site, long-term target remediation goals must be defined. These remediation goals should result in residual risks that are protective of human health and the environment. Use of these cleanup goals to screen remedial technologies early in the process will streamline the decision-making process. Chemical-specific cleanup goals for each environmental media can either be based on promulgated standards such as MCLs or on site-specific risks. Identification of these site-specific criteria depend upon which chemicals are present at the site, which environmental media are or may become contaminated, land-use assumptions, and exposure assumptions.

The sources of toxicity information will be limited to the Integrated Risk Information System (IRIS) (Micromedex, 1994) and the Health Effects Assessment Summary Tables (HEAST) (EPA, 1994). No attempt will be made to develop toxicity values from any other sources as part of this demonstration. Any uncertainties associated with developing remediation goals will be identified and discussed in the EE/CA. The potential impact of these uncertainties on the development of appropriate remediation goals will also be qualitatively evaluated.

The risk-based approach to remediation provides a more flexible and scientifically supportable basis for making remedial decisions. Identifying appropriate cleanup goals

for a site depends on site-specific data on probable land use and how potential receptors can and cannot come into contact with site-related contamination.

5.2.3.2.1 Air

Determination of air cleanup goals for a site depends on the current and probable land use of the area and the requirements of Risk Reduction Standard No. 3. For areas within or immediately downgradient of Site ST14 which may be available for limited residential use, air concentrations of COCs will not exceed an excess upperbound lifetime cancer risk of between one-in-ten thousand (10^{-4}) and one-in-one million (10^{-6}) for known or suspected carcinogens. Air concentrations of any COCs which are systemic toxicants will not present an appreciable risk of deleterious effect during a lifetime or part of a lifetime. Nonsystemic toxicant effects are factored into risk-based cleanup goals through the use of a hazard index. A hazard index is the sum of all hazard quotients for a single or multiple systemic toxicants which affect the same target organ or act by the same method of toxicity. A hazard index of one or less indicates that no appreciable noncarcinogenic risk due to inhalation exists. For areas subject to controlled use (e.g., through institution controls), concentrations of contaminants in air (either during or after remediation) will not exceed either OSHA permissible exposure limits, threshold limit values, or other criteria applicable to an industrial exposure setting. This approach is consistent with that required to demonstrate attainment with Risk Reduction Standard No. 3.

5.2.3.2.2 Soil

Risk-based remediation goals may be the only human health comparison criteria appropriate for soil at the site, as no appropriate promulgated standards may exist. Human health risk-based remediation goals can be developed for all the COCs by setting the carcinogenic target risk level at 10^{-6} and the hazard index at 1 for each group of the systemic toxicants which affect the same target organ or act by the same method of toxicity (EPA, 1991a).

Human health risk-based remediation goals for soil will be calculated using standard exposure assumptions appropriate for the exposure scenarios most representative of both current and potential future site conditions. As noted earlier, although the residential exposure scenario may result in the most stringent estimates of risk (and therefore require more stringent long-term concentration goals), this exposure scenario may not be representative of all types of exposures likely to be involved at this site. The industrial land-use assumption may be more appropriate for parts of Site ST14. The exposure pathways that are mostly likely to be incorporated into the soil remediation goals for the COCs include incidental ingestion of soil, inhalation of dust particulates, and inhalation of volatilizing COCs. In this way, the potential for cross-media contamination of air is included in the development of cleanup goals for soils. Standard default exposure variables recommended by EPA (1991d) will be used to develop risk-based soil cleanup goals. This approach is consistent with that recommended for demonstrating attainment with Risk Reduction Standard No. 3.

Cross-media contamination of ground water from contaminated soil will also be factored into the development of soil cleanup goals to ensure that soil is remediated to a level protective of ground water quality. Soil cleanup goals will also be determined to

protect air, and surface water quality. Fate and transport models, such as the Summers model and the air dispersion model discussed in Section 3.3, may be incorporated into this analysis to ensure that the selected remedial alternative minimizes cross-media contamination.

Chemical-specific concentration goals for soils that are protective of potential ecological receptors can be estimated by using chemical-specific ecological comparison criteria such as certain toxicological values documented in the scientific literature intended to be environmentally protective. Because many of these chemical-specific comparison criteria can be dependent upon other values (i.e., TOC, pH), data collection activities in support of demonstrating environmental protectiveness must involve measuring other influencing parameters. These requirements are briefly discussed in Section 4 of this TSTD/work plan. Observed or modeled concentrations at the point of exposure in the environmental media of concern (e.g., soil) are then compared to available comparison criteria. If contaminant concentrations meet or exceed available comparison criteria designed to be protective of ecological receptors, quantitative data will be used to determine the type and magnitude of remediation necessary to minimize risks.

5.2.3.2.3 Ground Water

Chemical-specific concentration goals for ground water can also be risk-based or based on promulgated standards, whichever is most appropriate for the site. Federal water quality and state drinking water standards are common promulgated remediation goals used to set ground water concentration goals. In addition, other types of laws, such as state antidegradation laws, may drive development of ground water remediation goals if they are accompanied by allowable concentrations of a chemical (i.e., qualitative direction is not equivalent to quantitative standards). The first step in determining which available concentration criteria may be appropriate for Site ST14 is to determine whether the ground water is a current or potential source of potable water. As noted previously, neither ground water nor surface water is used in the area as a potable water source. Lake Worth, which is upgradient of Site ST14, is the only source of drinking water for Forth Worth and the surrounding area.

According to EPA (1991a) risk guidance materials, if the aquifer can be demonstrated to not be a potential source of drinking water, then stringent state drinking water requirements or other health-based levels that assume some level of human ingestion are not appropriate ground water remediation goals. Additionally, federal guidance on ground water concentration goals (55 *Federal Register* 8717, 3/8/90) states that "ground water that is not an actual or potential source of drinking water may not require remediation to a 10^{-4} to 10^{-6} [risk] level (except when necessary to address environmental concerns or allow for other beneficial uses [such as agricultural use])." This means that environmental effects (such as potential impacts on biological receptors) and prevention of plume expansion can be used to determine long-term concentration goals for the ground water. The risk-based approach to remediation is designed to quantitatively investigate and implement appropriate remedial options that minimize contaminant migration and risks to potential receptors (including ecological receptors). This project will provide sufficient data to demonstrate that

proposed ground water remediation goals are consistent with the letter and intent of guidance on ground water concentration goals.

To identify and establish risk-based cleanup goals for ground water rather than promulgated standards, if appropriate, it will be necessary to demonstrate that the ground water is not a current or probable source of drinking water or hydraulically connected with or likely to migrate to either surface water or to ground water that is a current or potential source of drinking water. Generally, ground water that has a background total dissolved solids (TDS) content greater than 10,000 ppm, and occurs within a geologic zone that is not sufficiently permeable to transmit water to a pumping well in usable quantities, is not considered a current or potential source of drinking water. Further, if the remedial alternative includes institutional or legal controls that effectively prevent the use of the contaminated shallow ground water, it will also be unnecessary to remediate the ground water to drinking water levels. Finally, final ground water remediation goals can be modified to account for technology limitations. Thus, even if the ground water cannot be declared a nonpotable source of water, if the ground water cannot be restored to the levels dictated by stringent promulgated standards based on human ingestion criteria due to technological limitations, alternative cleanup goals are warranted.

Risk-based ground water cleanup goals will be developed to reflect site-specific conditions using the procedures described in EPA (1991a) OSWER Directive 9285.7-01B entitled *Human Health Evaluation Manual, Part B: Development of Risk-based Preliminary Remediation Goals*. EPA Directive 9481.00-6C will also be useful in developing risk-based ground water cleanup goals that ensure that the contaminant plume does not increase in size or concentration above allowable environmental exposure levels. Both of these approaches have been identified as appropriate in the TNRCC risk-reduction rule.

5.2.3.2.4 Surface Water

It is possible that surface water standards may also govern the development of ground water concentration goals for Site ST14 if the ground water migrates to and discharges into either Farmers Branch or the Trinity River. In this case, the "allowable" ground water concentration will be determined by investigating the fate and transport of the contamination, the potential concentration in the receiving surface water body at the point of discharge, and contaminant bioavailability. Surface water concentration goals can be based on the designated use of the water body such as for fishing or recreational. Surface water concentration goals that are designed to be protective of aquatic life may also be applicable. Any discharge or release into or adjacent to surface water will comply with the Texas Surface Water Quality Standards, Chapter 307. Actual chemical effects of ground water recharge or inflow from the oil/water separator on surface water quality, should this cross-media pathway be completed, may need to be investigated using one of the simple mixing models described in Section 3.3 of this TSTD/work plan.

5.2.3.3 Risk Determination

The goal of this demonstration is not to determine whether remedial action is warranted at the site, but rather to determine the type and magnitude of remedial action

required to minimize risks to human health and the environment to the maximum extent practicable. Thus the potential risks to human and ecological receptors will be determined by comparing calculated exposure concentration derived from field data and quantitative fate and transport analyses to the cleanup goals identified to be protective of human health and the environment given the site conditions. Comparison of these values will determine what type and magnitude of remediation will be necessary to minimize risks to the maximum extent practicable. If this comparison indicates that natural attenuation of site COCs is occurring and is sufficient to reduce the potential risks to human health and the environment to acceptable levels, ES will recommend implementation of natural attenuation with long-term monitoring as the preferred remedial alternative. The EE/CA prepared to demonstrate the effectiveness of the intrinsic remediation option will satisfy the requirements set forth at Sections 335.562 - 335.566 of the TNRCC risk-reduction rule.

5.2.4 Evaluation of Source Removal/Risk Reduction Options

To provide adequate data and analyses in support of the selection, design, and implementation of an appropriate remedial alternative for Site ST14, it will be necessary to critically evaluate single or combined remedial technologies in terms of long-term effectiveness, implementability, and cost. Field data, quantitative fate and transport modeling designed to explore the potential effectiveness of natural attenuation processes, and several other institutional and engineering technologies will be evaluated for their risk reduction potential. Combinations of institutional controls and cost-effective site remediation methods will be evaluated following the EE/CA process described in this section. Based on guidance from AFCEE, a minimum of three options will be evaluated for a site. Each option will be evaluated against three primary criteria: protectiveness of human health and the environment, implementability, and cost.

Protectiveness - Each remedial alternative will be analyzed to determine how effectively it will protect both current and future receptors from potential risks associated with COCs. This analysis will be based on determining whether the remedial alternative can achieve and maintain final cleanup goals. Protectiveness will also consider ecological receptors which may use surface waters downgradient of Site ST14. Protectiveness will also include permanence and ability to reduce contaminant mass, volume, and toxicity. Section 5.2.3 provides a more detailed description of the risk methods that will be used to determine the adequacy of protection.

Implementability - The technical implementation of each remedial option will be evaluated. The expected technical effectiveness of each remedial alternative will be described. Potential shortcomings and difficulties in construction, operations, and monitoring will be presented and weighed against perceived benefits. The administrative implementation (regulatory and community acceptance) of each remedial approach also will be discussed. This is an important element of the EE/CA, particularly when intrinsic remediation is determined to be the most cost-effective method of risk reduction.

Cost - The estimated cost of each remedial option will be presented. Both capital and operating costs will be estimated along with a present worth cost estimate for the

predicted operating life of each option. Cost assumptions will be clearly stated and the cost sensitivity of assumptions discussed.

It is important to note, however, that the most effective remedial technology or remedial alternative may not be the most cost-effective option for the site. Because the objective of this project is to identify, design, and implement the most cost effective remedial alternative at Site ST14, it will be necessary to apply the test of cost effectiveness. A cost effective remedial alternative is one that achieves the best balance between long-term effectiveness and cost of all the remedial alternatives which meet the cleanup objectives for the site. The test of cost effectiveness may be more extensive for a range of remedial alternatives which vary only in degree of long-term effectiveness, but which will all achieve the site cleanup goals. The remedial alternative which achieves the site cleanup goals at the lowest cost will be identified. The total cost for the other remedial alternatives will also be estimated, and all remedial alternatives will be ranked according to their degree of long-term effectiveness. The remedial alternative that provides the best balance between long-term effectiveness and cost would be the most cost-effective.

The following sections describe the remedial options that will, at a minimum, be considered for Site ST14 in accordance with the statement of work (SOW) and subsequent AFCEE project direction.

5.2.4.1 Intrinsic Remediation Only with Long-Term Monitoring

Fate and transport models described in Section 3.2 and 3.3 will be used to estimate the natural reduction of contaminants of concern due to biodegradation, adsorption, and dilution. The ability of this remedial option to naturally reduce risk under the scrutiny of long-term monitoring will be described. If sufficient risk reduction cannot be achieved through intrinsic remediation alone, the potential for unacceptable risk will be discussed along with institutional controls which could be implemented to eliminate or reduce contact between the COCs and the at-risk receptors.

5.2.4.2 Limited Source Removal

If the intrinsic remediation option does not provide adequate protection of human health or the environment, additional removal of the contaminant source will be required. Even if intrinsic remediation appears to be protective, the uncertainties of fate and transport models may necessitate that some level of active remediation be completed to reduce uncertainties associated with the long-term source of contamination. In these situations, the value of low-cost source removal technologies such as bioventing, free product removal, or biosparging will be evaluated. The selection of an appropriate source removal action will begin with a review of the site cleanup goals for soil and ground water. Using these cleanup goals, it will be possible to estimate the amount of additional source removal required to minimize risks to potential receptors and to protect environmental resources. In the case of downgradient ground water contamination, the Bioplume II data set will be modified to include the reduced source concentrations anticipated from the remedial option. The resulting reductions in soil and downgradient plume concentrations will then be compared against site-specific cleanup goals. Source removal will be increased until predicted

concentrations are significantly less than the cleanup goals. In some cases, two or more source removal technologies will be integrated in this option.

5.2.4.3 Intensive Source Removal and Ground Water Pumping

Immediate reductions in contamination can be achieved through more intensive source removal options such as soil vapor extraction and the extraction and treatment of contaminated ground water. Although this intensity of treatment may not be required based on the current or future risks posed by site contaminants, AFCEE has requested that the benefits and additional costs of intensive treatment be evaluated in the EE/CA.

5.2.5 Selection of a Recommended Approach

Based on an evaluation of the protectiveness, implementability, and cost of each option, ES will recommend the option which provides the greatest protection for the lowest cost. If the intrinsic remediation option provides this protection, a long-term monitoring plan will be developed to ensure that contaminant migration remains within predicted concentrations. If remediation of the source area is recommended, a conceptual design of the remediation system will be prepared and included in the EE/CA for Air Force and regulatory review. For Site ST14A, a conceptual design for a full-scale bioventing system has already been prepared (ES, 1993). If bioventing is selected for source removal, this design will be updated to include any areas of soil contamination discovered during the site investigation activities described in Section 4. If intrinsic remediation is an integral part of the recommended option, a long-term monitoring plan will be developed to ensure both soil and ground water contamination are decreasing according to the remediation strategy.

5.2.6 Long-Term Monitoring Plan

Upon completion of the field work phase of this demonstration project, quantitative fate and transport models will be coupled with the CSM to complete an exposure assessment for the site. As described in Section 5 of this TSTD/work plan, a tiered approach will be used to assess the potential effectiveness of various remedial alternatives at reducing or eliminating risks to potential receptors. If this analysis indicates that intrinsic remediation is sufficient to reduce the potential risk to human health and the environment, the most cost effective remedial alternative for the site will be intrinsic remediation and long-term monitoring. A site-specific, long-term monitoring plan will be included as part of the EE/CA which specifies the location of sentry and point-of-compliance wells and sampling frequencies necessary to demonstrate long-term effectiveness and permanence of the selected remedial alternative.

If quantitative data analysis indicates that intrinsic remediation will be insufficient alone to minimize receptor risks, other innovative source removal technologies will be evaluated. The reduction of source and dissolved BTEX that should result from additional remedial activities will be used in the quantitative fate and transport analyses for the site. Thus the models will be used to predict exposure pathway completion and exposure-point concentrations resulting from supplementing intrinsic remediation with other source removal technologies. Again, once the most cost-effective remedial alternative is identified, the EE/CA will include a long-term monitoring plan which will

contain any recommended plans for extended tests or sampling required to demonstrate the anticipated long-term effectiveness and permanence of the selected remedial alternative.

Following the implementation of any required source removal technologies at the site, ES will operate the source removal system for a total of 600 days. At the end of the 600 days of treatment ES will return to the site and resample soils and ground water in the source area to determine the degree of BTEX removal and evaluate the potential impact of source removal on the long-term fate and transport of dissolved- or vapor-phase contamination. A letter report will be prepared outlining the interim source removal results, the potential impact on the ground water plume and making recommendations for continued source removal if required.

5.3 REGULATORY COORDINATION STRATEGY

The risk-based approach described in this TSTD/work plan conforms to both EPA risk assessment guidance and Chapter 335 of the TNRCC (1993) Risk Reduction Standards. On 1 October 1993, an initial coordination meeting was held at Carswell AFB, with Mr Cecil Irby of the TNRCC and Mr. Sing Chi of EPA Region VI to describe, and obtain general concurrence with, the risk-based approach. The general approach was approved; however, both agency representatives requested an opportunity to review more site-specific information when it was available. Following AFCEE and base review of this TSTD/work plan, an information copy will be forwarded to these two regulatory representatives. It may be advantageous to hold another meeting with representatives of TNRCC and EPA to verify their support since it has been over 8 months since the initial meeting.

The EE/CA will serve as the primary document for obtaining regulatory approval for the risk-based remediation approach. This document will contain all of the supporting data to satisfy the requirements of relevant EPA (1989-1993) risk assessment guidance material and the TRNCC (1993) risk-reduction standards. The EE/CA will provide quantitative evidence of intrinsic remediation and develop final cleanup goals for each affected environmental medium based on risk criteria. If source removal is required, the EE/CA will provide a conceptual design that is in sufficient detail to gain regulatory approval to proceed with the remediation. A long-term monitoring plan will be provided to ensure that the predictions of fate and transport modeling can be verified and that contaminants of concern do not migrate at concentrations which could cause an unacceptable risk to human or ecological receptors. Sentry and point-of-compliance wells will be established to verify that intrinsic remediation is occurring and that plume migration is limited.

Following AFCEE and base review of the draft EE/CA, their comments will be incorporated into a final draft for regulatory review and approval. When the final draft is completed, AFCEE and ES will provide a technical presentation to base officials and regulatory agencies to familiarize them with the key findings and recommendations of the EE/CA. Copies of the EE/CA will be provided to regulators at the meeting and a 30 day review will be requested.

SECTION 6

PROPOSED PROJECT SCHEDULE

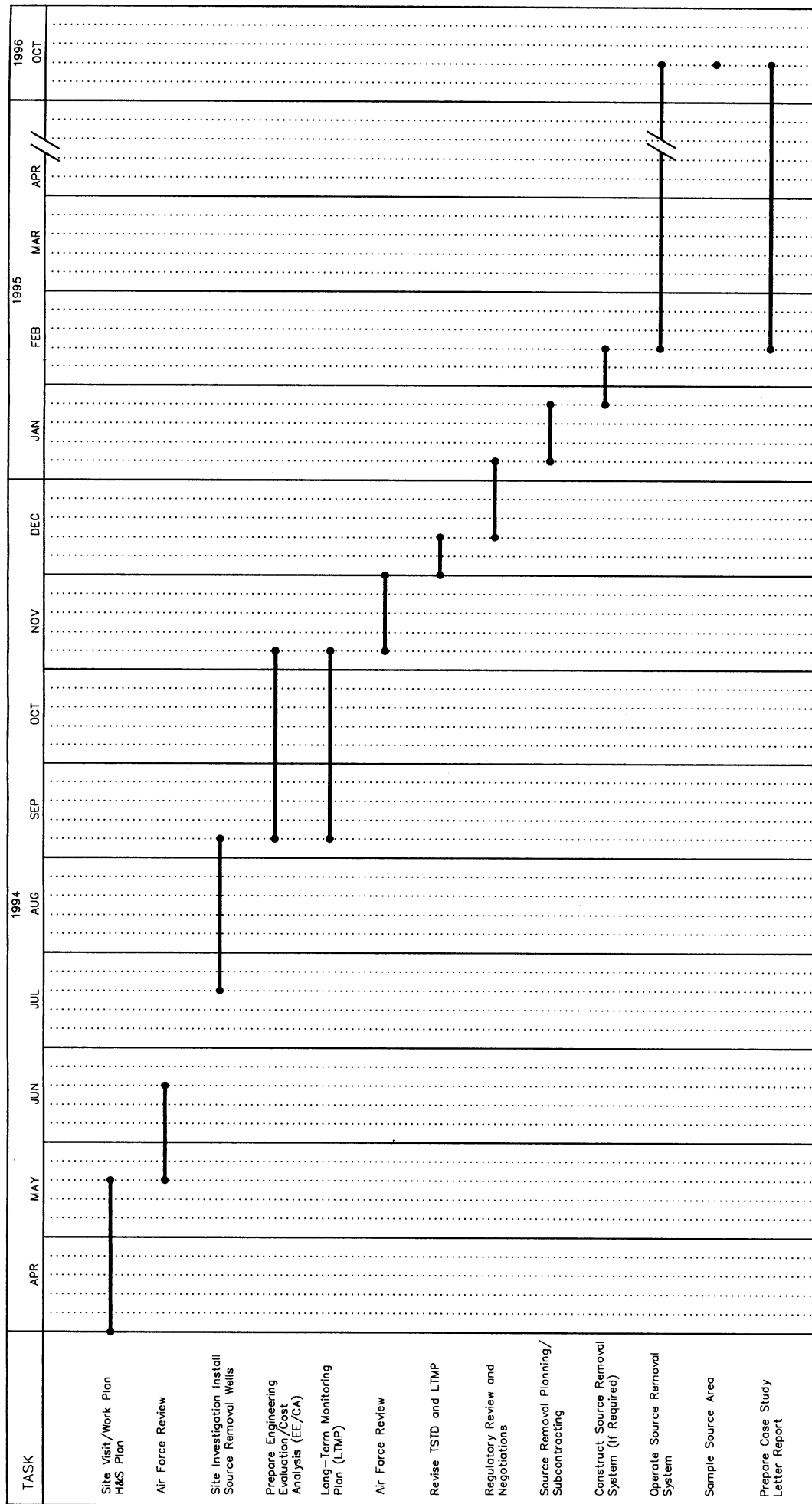
The following timeline details the proposed duration of and date of completion for each of the major tasks involved in evaluating, selecting, designing, and implementing a remedial alternative for Site ST14 which minimizes contaminant migration and risks to potential receptors. Each of these major tasks is described in other sections of this TSTD/work plan.

SECTION 7

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FIGURE 6.1 RISK-BASED DEMONSTRATION SCHEDULECARSWELL AFB SITE ST14



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SITE SAMPLING AND ANALYSIS PLAN
FOR
RISK-BASED REMEDIATION DEMONSTRATIONS
AT SITE ST14, CARSWELL AFB

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The purpose of this site-specific sampling and analysis plan (SAP) is to provide the procedures to be followed when collecting additional data in support of the risk-based approach to remediation at Site ST14. Details on analytical requirements, desired quantitation (detection) limits, and proposed sample locations are identified within section 4 of the TSTD/work plan. Specific health and safety requirements are described in both the program health and safety (H&S) plan and the site-specific addendum (Appendix B). The need to collect additional samples to meet quality assurance requirements are described in the program quality assurance project plan (QAPP). Specific quality assurance sampling requirements for Site ST14 are summarized herein as part of the site-specific sampling procedures. These additional samples will be used to determine the precision, accuracy, completeness, and representativeness of the final data set.

Soil gas sampling is described in section 1; soil flux sampling is described in section 2; drilling, soil sampling, lithologic logging, and bioventing and ground water monitoring well installation procedures are described in section 3; ground water sampling procedures are described in section 4; aquifer testing procedures are described in section 5; surface water sampling procedures are described in section 6; and field quality assurance/quality control (QA/QC) samples are described in section 7.

A.1 SOIL GAS SAMPLING

Soil gas will be used as an indicator of subsurface hydrocarbon contamination and to assess the feasibility of using bioventing to remove source contamination at the site. The use of soil gas to delineate potential subsurface contamination and to determine bioventing feasibility has several economic and technical advantages over more traditional drilling and soil sampling techniques. The labor and equipment cost can be significantly less than a conventional drilling and sampling team. Many new hydraulically driven, multi-purpose probes can be used for soil gas sampling. These probes can be advanced as quickly as conventional augers and do not produce drill cuttings which can require expensive analysis and disposal. Further, soil gas sampling can represent the average chemistry of several cubic feet of soil as compared to a discrete soil sample, which can only describe a few cubic inches of the subsurface. This is of particular importance in risk-based remediation projects where the extent of COC contamination and the degree of removal of COCs can most accurately be determined by using multiple soil gas sampling locations.

However, collection of soil gas from very moist soils and particularly fine-grained units can be technically infeasible. Moreover, collection of soil gas samples from low-permeability soils often result in the leakage of atmospheric air into the sampling system and causes inaccurate results. Deep contamination and contamination in tight or cobble soil are still best assessed using standard drilling techniques rather than soil gas probes.

The test equipment and methods that will be required to conduct field soil gas surveys as part of the risk-based remediation at this site are described fully in the AFCEE document *Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential* (AFCEE, 1994). In summary, the soil gas survey will be conducted first at this site to determine the areal extent and possible shallow vertical extent of soil gas and soil contamination. Results from this

survey will be used to guide soil drilling, sampling, and well installation. Data from this survey will also be used to determine if bioventing is a necessary and feasible source removal technique for the site. For example, if the soil gas survey indicates that sufficient oxygen (O_2) is naturally available and distributed throughout the subsurface, bioventing may not be required to enhance fuel biodegradation rates (AFCEE, 1994).

Soil gas sampling will be conducted using small-diameter [approximately 5/8- to 1-inch outside-diameter (OD)] stainless steel probes. The typical probe consists of a drive point with a retractable, perforated tip that is threaded onto a series of drive rod extensions. The soil probe is fitted with a replaceable stainless steel screen to prevent fine-grained soils from clogging the perforations. Before use, 1/8-inch-diameter flexible Tygon™ tubing is connected to the soil probe and passed through the center of the drive rods. The 1/8-inch Tygon™ tubing, which is used to collect the soil gas samples, extends from the soil probe to the purge pump or sampling device at the surface. A new section of Tygon™ tubing will be used for each sampling point.

A digging permit from Carswell AFB and utility clearances must be obtained prior to probe use. The primary utilities in the investigation area are buried fuel transfer lines and buried electrical lines. Temporary probes utilize either a hand-driven electric hammer or a hydraulic ram. Soil texture and sample depth requirements must be evaluated before determining which probe is best for the site. A hand-driven electric hammer soil gas probe should be sufficient for the conditions and data needs at Site ST14 at Carswell AFB.

Gaseous concentrations of carbon dioxide and oxygen will be analyzed onsite using an O_2/CO_2 analyzer. The analyzer will generally have an internal battery-powered sampling pump and range settings of 0 to 25 percent for both oxygen and carbon dioxide. Before analyzing samples collected with the soil gas probe, the analyzer must be checked for battery charge level. The analyzer will also be calibrated daily using atmospheric conditions of oxygen (20.9 percent) and carbon dioxide (0.05 percent) and a gas standard containing 0.0 percent oxygen and 5.0 percent carbon dioxide.

Total volatile hydrocarbon (TVH) concentrations will be used as the primary screening tool at this site. The TVH analyzer used at Site ST14 will be capable of measuring hydrocarbon concentrations in the range of 1 to 20,000 parts per million, volume per volume (ppmv). The analyzer must also distinguish between methane and non-methane hydrocarbons. The battery charge level on the TVH analyzer will be checked prior to analysis of each collected soil gas sample. The TVH analyzer will also be calibrated daily using a hexane calibration gas.

All soil gas samples taken during the first-phase of the planned soil gas survey will be collected using 3-liter Tedlar™ bags and vacuum chambers. The soil gas sample will then be analyzed by attaching the O_2/CO_2 and TVH analyzers directly to the Tedlar™ bag. Those sample locations identified for compound-specific analysis will be re-sampled using 3-liter Tedlar™ bags and vacuum chambers. The sample will then be transferred to 1-liter SUMMA™ canisters and shipped to the laboratory for compound-specific analysis using EPA method TO-3 (see Table 4.1 in the TSTD/work plan).

Field QA/QC procedures for soil gas will include collection of one field duplicate, one sampling equipment blank, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical

laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., soil gas), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used.

In order to determine if sampling equipment is free from contamination, a sampling equipment blank will be collected. The sampling equipment blank will be collected by assembling the sampling probe and collecting an ambient air sample in a Tedlar™ bag. The equipment blank will be analyzed in the field using the TVH analyzer. An ambient air reading using the TVH analyzer will be obtained immediately prior to obtaining the reading from the Tedlar™ bag containing the sampling equipment blank. A comparison between the TVH analyzer readings for the ambient air and sampling equipment blank will give an indication if the sampling equipment is free from contamination.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Soil gas QA/QC sampling will include only one duplicate. However, the laboratory should also plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested for soil gas (i.e., required only once for soil gas extracted via soil gas probe or obtained via flux chamber).

A.2 SOIL FLUX SAMPLING

Several soil flux tests will be conducted at the site to determine the natural background emissions from the site. The purpose of these flux tests is to estimate potential air quality impacts from COC emissions from contaminated environmental medium. Flux samples will be collected at Site ST14 using the procedures outlined in EPA guidance *Measurement of Gaseous Emissions Rates from Land Surfaces Using a Emission Isolation Flux Chamber* (EPA, 1985). The use of a flux box is the preferred method of measurement of surface emission rates of volatile contaminants. A flux box is used to isolate a known surface area from the ambient air, collect surface emissions, and mix the collected emissions with "sweep" air introduced into the chamber at a known flow rate. Data from the flux box can then be combined with a simple dispersion model (such as those described in section 3.3 of the TSTD/work plan) to identify potential ambient air contamination impacts.

The detection limits presented in Table 4.1 within the TSTD/work plan are sufficient for the required sensitivity for the compound-specific analysis using a flux box. Site ST14 has already been divided into zones to support the analysis of potential risks due to surface emissions. Flux sample locations are identified on Figure 4.1 within the TSTD/work plan. Sample locations have been sited in background, potential source areas, areas overlying potential dissolved-phase ground water contamination, and areas downgradient of suspected soil and ground water contamination. The zone emission rates will not be averaged on an area basis. Rather the data will be used to characterize potential rates of emission for different areas of the site. This approach will support establishment of site-specific remediation goals that are protective of air quality.

The procedures contained within EPA's protocol document on measuring emission rates (i.e., Measurement of Gaseous Emission Rates from Land Surfaces using an Emission Isolation Flux Chamber (EPA/600/8-86/008)) will be followed. In summary, gaseous emissions will be collected from an isolated surface area using a flux chamber and monitored using both "real-time" and discrete methods. Real-time measurements will be made with a portable hydrocarbon analyzer to determine when the chamber reaches steady-state conditions. Discrete samples will then be collected for chemical analysis.

To reduce the potential for cross-contamination, which can occur whenever high level or low level samples are sequentially analyzed, the flux chamber will be purged and tested with a blank after each sample is conducted. Emission tests will only be conducted when soil moisture levels are normal. Increased ground moisture as a result of rain or heavy dew can bias (lower) emission rates.

The sweep air to be used will be dry, organic free air equal to or better than commercial ultra high purity grade (< 0.1 ppmv total hydrocarbon content). Discrete samples will be collected in SUMMATM canisters and analyzed using EPA Method TO-3 to identify BTEX concentrations.

Field QA/QC procedures for soil flux sample will be identical to those required for soil gas. QA/QC requirements include collection of one field duplicate, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., soil gas), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Soil flux QA/QC sampling will include only one duplicate. However, the laboratory should also plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested for soil gas (i.e., required only once for soil gas extracted via soil gas probe or obtained via flux chamber).

A.3 DRILLING, SOIL SAMPLING, AND BIOVENTING AND GROUND WATER MONITORING WELL INSTALLATION

To further characterize the hydrogeologic conditions of the shallow soil and ground water for quantitative fate and transport analyses using the Bioplume II model, up to 30 new wells will be installed at Site ST14. The following sections describe the proposed well locations and completion intervals, equipment decontamination procedures, drilling and soil sampling, well installation, well development procedures, and well location and datum surveying. All drilling, soil sampling, and well installation will proceed from areas suspected to be least contaminated to areas suspected to be more contaminated.

A.3.1 Well Locations and Completion Intervals

Approximately 30 new wells will be installed to further characterize soil and ground water quality at the site, and support source removal activities if necessary. These wells will be screened from 3 feet above the ground water table to the well completion depth. Appropriate

screen intervals will be placed in all new wells depending on their intended purpose. Depths to ground water in the Upper Zone Aquifer range from 6 to 16 feet bgs, whereas depth to the Goodland Formation is about 16 to 20 feet bgs. Well completion depths for bioventing wells are expected to range between approximately 4 and 16 feet bgs. Well completion for ground water wells will range from 16 to 20 feet bgs. The new well locations were selected to provide the hydrogeologic data necessary for successful implementation of the Bioplume II model and to support source removal activities as necessary. Figure 4.2 in the body of the TSTD/work plan shows the proposed well locations.

A.3.2 Drilling and Soil Sampling Procedures

This subsection addresses the procedures for drilling soil borings that will be used for soil sampling and completed as new wells. All new monitoring wells will be installed in accordance with general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987).

A.3.2.1 Pre-Drilling Activities

All necessary digging, drilling, and well installation permits will be obtained prior to mobilizing to the field. In addition, all utility lines will be located and proposed drilling locations cleared prior to any drilling activities.

A.3.2.2 Equipment Decontamination Procedures

Water to be used in drilling, equipment cleaning, or grouting will be obtained from one of the base's onsite water supplies. Water use approval will be verified by contacting the appropriate facility personnel. Only potable water will be used for the activities listed above. A decontamination water blank will be collected from the potable water source. The procedures for the collection of the decontamination water blank will be described in Section A.7. The ES field hydrogeologist will make the final determination as to the suitability of site water for these activities.

Prior to arriving at the site, and between each drilling site, the drill rig, augers, drilling rods, bits, casing, samplers, tools and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

During drilling operations, the drill rig, augers, and any down-hole drilling and/or sampling equipment will be decontaminated at the Carswell AFB decontamination pad or another location specified by base personnel. Water from the decontamination operations will be allowed to collect in the decontamination pad collection tanks. Precautions will be taken to minimize any impact to the area surrounding the decontamination pad that might result from the decontamination operations. If equipment is decontaminated in another location, a temporary decontamination pad will be constructed. The temporary decontamination pad will be constructed in a manner so as to contain all decontamination fluids. All decontamination fluids generated at the temporary decontamination pad will be placed in 55-gallon drums. The decontamination fluids will be disposed of following the procedures presented in Section A.3.5.

All sampling tools will be cleaned onsite, prior to use and between each sampling event, with a clean water/phosphate-free detergent mix and a clean water rinse. All well completion

materials that are not factory sealed will be cleaned onsite prior to use with a high-pressure, steam/hot water wash using approved water. Materials that cannot be cleaned to the satisfaction of the ES field hydrogeologist will not be used. All decontamination activities will be conducted in a manner so that the excess water will be controlled and not allowed to flow into any open borehole.

If contaminated soils are encountered during drilling [based on visual, olfactory, or volatile organic analyzer indications], and the potential for cross-contamination is anticipated, drilling will be stopped and modified drilling procedures will be implemented to prevent the transfer of contaminants to deeper strata.

Fuel, lubricants, and other similar substances will be handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials will not be stored near or in areas which could be affected by these substances. The drill rigs will not be allowed onsite unless they are free from leaks in any hydraulic lines, and are free of any exterior oil and grease.

Surface runoff such as miscellaneous spills and leaks, precipitation, and spilled drilling fluid will not be allowed to enter any boring or well either during or after drilling/well construction. To prevent this from happening, starter casing, recirculation tanks, berms around the borehole, and surficial bentonite packs, as appropriate, will be used.

A.3.2.3 Drilling and Soil Sampling

Drilling in unconsolidated soils will be accomplished using hollow-stem augers. The borings will be drilled and continuously sampled to the proposed total depth of the monitoring well. A final borehole diameter of at least 10 inches will be required for the installation of bioventing air injection wells (downgradient of the source) with 4-inch inside-diameter (ID) casing. Auger ID will not be less than 5 inches. For installation of ground water monitoring wells, the auger ID will not be less than 4 inches. Determination of well completion details will be at the discretion of the ES field hydrogeologist. It is likely that most boreholes will be drilled to a final diameter of 10 inches within the suspected source area.

If subsurface conditions are such that the planned drilling technique does not produce acceptable results (e.g. unstable borehole walls or poor soil sample recovery) another technique deemed more appropriate to the type of soils present will be used. Any alternate soil sampling procedure used must be approved by the ES field hydrogeologist and will be appropriate for the subsurface lithologies present at the site.

Continuous soil samples will be obtained using a CME[®] split-barrel continuous sampling device or another similar method judged acceptable by the ES field hydrogeologist. Samples will be collected in 2-foot intervals through the capillary fringe smear zone to below the ground water table. The ES field hydrogeologist will identify which samples from the continuous sampling device will be submitted for chemical analysis. Only soils that exhibit possible contamination will be retained for chemical analysis. One goal of the sampling is to collect at least one sample from the interval exhibiting the most concentrated fuel contamination. Soil samples which may be retained for chemical analysis will be placed in sample containers immediately after the core barrel is opened. A maximum of three soil samples for chemical analysis will be collected per borehole. All soil cores will be evaluated for lithologic

characteristics, however. All soil samples collected will be removed from the continuous sampler and placed on clean aluminum foil for logging.

Every 2-foot soil sample recovered will be subsampled, composited, and placed in a clean container for PID or similar hydrocarbon vapor analyzer headspace measurements for VOCs. Representative portions of the soil samples collected for the headspace procedure will be quickly transferred to the sample containers, which will be sealed and held for 15 minutes at an ambient temperature of 65 degrees Fahrenheit (°F) or greater. Semiquantitative measurements will be made by puncturing the container seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID will be calibrated daily to 100 parts per million, volume per volume of isobutylene. It is anticipated that headspace measurements will be performed on all samples collected during the drilling operations to determine which soil samples will be submitted for chemical analysis. The PID will also be used to monitor the worker breathing zone.

As a check on the quality of field sampling activities (sampling, containerization, shipment, and handling) QA/QC trip blanks, field blanks, equipment rinseate samples, and field duplicates will be sent to the laboratory. QA/QC sampling will include duplicates for up to nine soil samples (i.e., frequency of 10 percent), a total of nine rinseate samples (i.e., frequency of 10 percent), one field blank, and a trip blank for each individual cooler sent to the analytical laboratory. The procedures for the collection of field QA/QC samples are discussed below in Section A.7. Laboratory QA/QC procedures will include one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested.

The ES field hydrogeologist will be responsible for observing all drilling and well installation activities, maintaining a detailed descriptive log of subsurface materials recovered, photographing representative samples, and properly labeling and storing samples. An example of the proposed geologic boring log form is presented in Figure A.1. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination;
- Soil or rock description, including: relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations;
- Lithologic contacts: the depth of lithologic contacts and/or significant textural changes will be measured and recorded to the nearest 0.1 foot (1 inch); and
- Determination on whether soil sample will be submitted for chemical analysis or segregated as uncontaminated medium.

A.3.2.4 Minimization and Management of Drilling Residuals

Drilling activities will generate soil cuttings requiring proper handling and, if contaminated, proper disposal. Based on data from previous soil sampling efforts at the site, which indicate little contamination above the smear zone, only cuttings from the capillary fringe are expected to be contaminated. Care will be taken to segregate uncontaminated near-surface soils from soils containing fuel residuals. Soils will be screened using a PID or similar hydrocarbon vapor analyzer. Clean soils will be placed on plastic or separated from potentially contaminated media, and then spread on the ground along the eastern fence of the Fuel Loading Area. Contaminated soils will be drummed and placed in an onbase staging area. Two composite samples from the contaminated soil placed in the drums will be collected and analyzed by EPA Method 8020. Approximately 10 barrels of contaminated soil and 15 barrels of clean soils are anticipated during this limited drilling event. If required, ES will biologically treat barrels of contaminated soil using a side stream from the existing pilot bioventing system until BTEX is reduced to acceptable levels for spreading on the ground.

A.3.3 Bioventing Well Installations

The potential for vadose soil contamination will be determined at three or four soil borings immediately east of Buildings 1213 and 1214 and between Tanks 1156 and 1157. If continuous soil coring reveals that the fuel-contaminated interval exceeds 2 feet, that boring will be completed as a bioventing air injection well and later included in a possible full-scale bioventing system for reducing contamination in these source areas. These additional 4-inch-diameter bioventing wells will be completed using the same design as existing pilot bioventing wells (ES, 1993).

A.3.4 Ground Water Monitoring Well Installation

Ground water monitoring wells will be installed in each of the 30 soil borings not completed as bioventing wells at Site ST14. Except where specified, the entire thickness of the Upper Zone Aquifer will be screened. Detailed well installation procedures are described in the following paragraphs. A typical well completion diagram is included as Figure A.2.

A.3.4.1 Well Material Decontamination

Well completion materials will be inspected by the ES field hydrogeologist and determined to be clean and acceptable prior to use. If not factory sealed, casing, screen, and casing plugs and caps will be cleaned with a high-pressure, steam/hot water cleaner using approved water prior to use. Prepackaged sand, bentonite, and Portland[®] cement will be used in well construction, and the bags will be inspected for possible external contamination before use. Materials that cannot be cleaned to the satisfaction of the ES field hydrogeologist will not be used.

A.3.4.2 Well Casing

Upon completion of drilling to the proper boring termination depth, a monitoring well casing will be installed. Well construction details will be noted on a Monitoring Well Installation Record form, as shown in Figure A.3. This information will become part of the permanent field record for the site.

Blank well casing will be constructed of Schedule 40 polyvinyl chloride (PVC) with an ID of 2 inches. All well casing sections will be flush-threaded; glued joints will not be used. The

casing at each well will be fitted with a threaded bottom plug and a top cap constructed of the same type of material as the well casing. The top cap will be vented to maintain ambient atmospheric pressure within the well casing.

The ES field hydrogeologist will verify and record the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus casing and borehole wall. All lengths and depths will be measured to the nearest 0.1 foot.

A.3.4.3 Well Screen

Well screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 2 inches. The screens will be factory slotted with 0.010-inch openings. Each well will be screened so that seasonal fluctuations of the water table can be measured. The water level in the unconfined aquifer will be allowed to fluctuate within the screened interval. The position of the screen will be selected by the ES field hydrogeologist after consideration is given to the geometry and hydraulic characteristics of the stratum in which the well will be screened.

A.3.4.4 Sand Filter Pack and Annular Sealant

A graded sand filter will be placed around the screened interval and will extend at least 2 feet above the top of the screen. The sand filter will consist of 10-20 silica sand. An annular seal will be placed above the gravel pack using sodium bentonite pellets. The pellet seal will be a minimum of 2 feet thick and will be hydrated in place with potable water. The pellet seal will be overlain by a Portland\ cement/sodium bentonite grout that will extend from the top of the pellet seal to approximately 3 feet bgs. The Portland[®] cement/sodium bentonite grout will consist of one 94-pound sack of cement and about 5 pounds of bentonite for each 7 gallons of water used. The bentonite content of the cement/bentonite will not exceed 8 percent by dry weight. The grout will be overlain with concrete to the ground surface. To reduce heaving of the newly-installed monitoring well caused by freeze-thaw processes, it is imperative that the uppermost concrete seal extend to at least the maximum frost line.

A.3.4.5 Flush-Mount Protective Cover

Each monitoring well will be completed with an at-grade (flush-mount) protective cover. In areas where pavement is present, the at-grade cover will be cemented in place using concrete which will be blended to the existing pavement. In areas where pavement is not already present, a 6-inch thick, 2-foot-diameter concrete pad will be constructed around the protective cover. In either case, the concrete immediately surrounding the well cover will be sloped gently away from the protective casing to facilitate runoff during precipitation events.

A.3.5 Well Development

Before any new well can be considered in proper condition for monitoring water levels or taking water samples, it must be developed. Development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. If a well is grouted prior to development, well development will occur no sooner than 48 hours after grouting of the annulus is completed.

Well development will be accomplished using dedicated disposable bailers or a peristaltic pump. The bailer or pump will be lowered to the bottom of the well so that fines which have accumulated in the bottom are agitated and removed from the well in the development water.

Development will be continued until a minimum of three casing volumes of water have been removed from the well and the water pH, temperature, and specific conductivity have stabilized. Temperature, pH and specific conductivity will be monitored during development (one reading for each parameter per well volume). Pumping will continue until these parameters have stabilized to within 10 percent among four consecutive readings and the water is clear and free of fines. The pH and specific conductivity meters will be calibrated on a daily basis. The pH meter will be calibrated by laboratory-prepared standard solutions following the manufactures calibration procedures. The specific conductivity meter will be calibrated using laboratory-prepared known conductivity solutions. If the development water still is turbid after removal of three casing volumes, development will be continued until the water becomes clear or the turbidity of the water produced has been stable after the removal of several casing volumes.

The development procedure specifies that three casing volumes of water be removed from the well. However, some wells completed in marginal aquifers will go dry during well development prior to the recovery of three casing volumes. In these low-productivity wells, development activity may have to be staged over a period of time to allow water to refill the well bore. In the event three casing volumes of water cannot be recovered, the water volume recovered will be noted in the development records.

All well purge water will be placed in 55-gallon drums. At the end of the field sampling event the drums will be air sparged to remove any remaining BTEX. Water in each drum will be sampled and analyzed using EPA Method SW8020. If the analysis indicates BTEX concentrations are below their respective MCLs, the water will be discharged into the sanitary sewer. No free product is anticipated in new wells. If free product is encountered, it will be disposed of in the 55-gallon drum located next to ST14-17M. Waters that are contaminated (visibly or as indicated by PID headspace readings) will be collected in 55-gallon drums and transferred to Carswell AFB personnel for treatment and disposal.

A.3.6 Well Development Records

A record of well development will be maintained for each well. The well development record will be maintained in a bound field notebook by the field hydrogeologist. Figure A.4 is an example of the well development record. A summary well development record form will be prepared for each well and submitted with the EE/CA report. Development records will include:

- Well number;
- Date and time of development;
- Development method;
- Predevelopment water level and well depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and well depth; and

- Field analytical measurements, including pH and specific conductivity.

A.3.7 Water Level Measurements

Water levels at all wells will be measured within a short time interval so that the water-level data are comparable. Water levels in the new wells will not be measured until they are developed and the water level has stabilized. The depth to water below the measurement datum will be made using an oil/water interface electric probe to the nearest 1/8 inch (0.01 foot). The oil/water interface probe will be decontaminated prior to use, and between each measurement, following the decontamination procedures presented in Section A.4.3. In addition, water level measurements will be made in select bioventing wells and ground water monitoring wells at the site that will not be sampled for chemical analysis. This data will be used to calibrate the Bioplume II model and describe hydrogeologic characteristics.

A.3.8 Well Location and Datum Survey

The location and elevation of the new wells will be surveyed by a registered surveyor soon after well completion. Horizontal locations will be measured relative to established Carswell AFB coordinates. Horizontal coordinates will be measured to the nearest 0.01 foot. Vertical location of the ground surface adjacent to the well casing, the measurement datum (top of the interior casing), and the top of the outer well casing will be measured relative to a USGS MSL datum. The ground surface elevation will be measured to the nearest 0.1 foot, and the measurement datum, outer casing, and surveyor's pin (if present) elevation will be measured to the nearest 0.01 foot.

A.3.9 Site Restoration

After well installation and sampling is complete, each well site will be restored as closely to its original condition as possible.

A.4 GROUND WATER SAMPLING

This section describes the scope of work required for collecting ground water samples at each of the 30 new wells developed as ground water wells, the 11 existing ground water monitoring wells, and 3 bioventing wells to be used to evaluate ground water quality. All water samples collected from ground water monitoring wells or bioventing wells will be obtained using either disposable bailers or a thoroughly decontaminated peristaltic pump. In order to maintain a high degree of quality control during this sampling event, the procedures described in the following sections will be followed.

Ground water sampling will be conducted by qualified ES scientists and technicians trained in the conduct of well sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed the TSTD/work plan and this site-specific sampling and analysis plan prior to sample acquisition and will have a copy of both available onsite for reference.

Activities that will occur during ground water sampling are summarized below:

- Assembly and preparation of equipment and supplies;

- Inspection of the well integrity, including:
 - Protective cover, cap and lock,
 - External surface seal and pad,
 - Well stick-up, cap, and datum reference,
 - Internal surface seal,
 - Condition of bladder pump if present;
- Ground water sampling, including:
 - Water-level measurements,
 - Visual inspection of borehole water,
 - Well casing evacuation,
 - Sampling;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters,
 - Sample labeling;
- Completion of sampling records;
- Completion of chain-of-custody records; and
- Sample disposition.

Detailed ground water sampling and sample handling procedures are presented in following sections.

A.4.1 Ground Water Sampling Locations

Ground water samples will be collected from a maximum of 30 newly installed ground water monitoring wells, 11 existing wells, and 3 bioventing wells using either a disposable bailer or a thoroughly decontaminated peristaltic pump.

A.4.2 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all recordkeeping materials will be gathered prior to leaving the office.

A.4.3 Equipment Decontamination

All portions of sampling and test equipment that will contact the sample will be thoroughly cleaned before each use. This equipment includes the peristaltic pump and tubing, water-level probe and cable, oil/water interface probe and cable, lifting line, test equipment for onsite use, and other equipment or portions thereof which will contact the samples. Based on the types of sample analyses to be conducted, the following decontamination protocol will be used:

- Clean with potable water and phosphate-free laboratory detergent;
- Rinse with potable water;
- Rinse with distilled or deionized water;
- Rinse with reagent-grade isopropanol; and
- Air dry the equipment prior to use.

All decontamination fluids will be contained in 55-gallon drums, treated, and disposed of as described in Section A.3.5. Any deviations from these procedures will be documented in the field scientist's field notebook and on the ground water sampling form. If pre-cleaned dedicated sampling equipment is used, the decontamination protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory and therefore will not need to be cleaned in the field.

A.4.4 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturer's specifications prior to field use. This applies to equipment used for onsite chemical measurements such as pH, electrical conductivity, and temperature.

A.4.5 Sampling Procedures

Special care will be taken to prevent contamination of the ground water and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and by cross-contamination through insufficient decontamination of equipment between wells. To prevent such contamination, the peristaltic pump and water level probe and cable used to determine static water levels and well total depth will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section A.4.3. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile gloves will be worn each time a different well is sampled. Wells will be sampled sequentially from areas suspected to be least contaminated to areas suspected to be more contaminated.

The following paragraphs present the procedures that comprise ground water sample acquisition from all ground water sampling locations. These activities will be performed in the same order as presented below. Exceptions to this procedure will be noted in the ES field scientist's field notebook.

A.4.5.1 Preparation of Location

Prior to starting the sampling procedure, the area around the well will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well.

A.4.5.2 Water Level and Total Depth Measurements

Prior to removing any water from the well the static water level will be measured. An electrical water level probe will be used to measure the depth to ground water below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly

lowered to the bottom of the well and the total well depth will be measured to the nearest 0.01 foot. Based on these measurements the volume of water to be purged from the well can be calculated.

Emphasis will also be placed on defining the probable areal extent of any remaining free fuel product that may act as a continuing source of contamination at the site. Free product can be physically identified during drilling and soil sampling and through the use of an oil/water interface probe. Moreover, ground water samples showing a benzene concentration equal to or in excess of 178 mg/L (10 percent of its maximum solubility in water) will be operationally defined as potential fringe areas to oily-phase contamination (or underlying significant residual soil contamination).

A.4.5.3 Well Purging

The volume of water contained within the well casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well. The pH, temperature, and specific conductivity will be monitored during well purging. Purging will continue until these parameters have stabilized to within 10 percent among three consecutive readings. All purge water will be placed in 55-gallon drums, treated, and disposed of as described in Section A.3.5. The empty drums will be rinsed with hot water and returned to base personnel for reuse. Disposable bailers or a thoroughly cleaned peristaltic pump will be used for well evacuation.

If a well is evacuated to a dry state during purging, the well will be allowed to recharge to 80 percent of its original water level and the sample will be collected as soon as sufficient water is present in the well to obtain the necessary sample quantity. Sample compositing, or sampling over a lengthy period by accumulating small volumes of water at different times to eventually obtain a sample of sufficient volume, will not be allowed.

A.4.5.4 Sample Extraction

Either disposable, polyethylene bailers or a thoroughly decontaminated peristaltic pump will be used to extract ground water samples from the well. Both types of extraction equipment will be lowered into the water gently to prevent splashing and extracted gently to prevent creation of an excessive vacuum in the well. The sample will be transferred directly to the appropriate sample container. The water sample will be transferred from the bottom of the bailer using a bottom emptying device to allow a controlled flow into the sample container. Water for the peristaltic pump can be directly discharged into the sample container. The water should be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be placed into the 55-gallon drums used for well purge waters and transferred to Carswell AFB personnel for disposal.

A.4.6 Onsite Chemical Parameter Measurement

Dissolved oxygen (DO) measurements will be taken onsite using a meter with a downhole oxygen sensor. The DO meter will be decontaminated, prior to each use, following decontamination procedures described in Section A.4.3. DO measurements will be taken

immediately following ground water sample acquisition. Where DO measurements will be taken in wells which have not been sampled, the well will be purged as described earlier prior to taking the DO measurement.

Because the pH, temperature, and specific conductance of a ground water sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean glass container separate from those intended for laboratory analysis and the measured values will be recorded in the ground water sampling record.

A.4.7 Sample Handling

This section describes the handling of samples from the time of sampling until the samples arrive at the laboratory.

A.4.7.1 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory. The sample containers will be filled as described in Section A.4.5.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (ground water, surface water, etc.);
- Sampling date;
- Sampling time;
- Preservatives added; and
- Sample collector's initials.

A.4.7.2 Sample Preservation

The laboratory will add any necessary chemical preservatives prior to shipping the containers to the site. Samples will be properly prepared for transportation to the laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C).

A.4.7.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the AFCEE-approved laboratory for this demonstration. The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Label shipping container with:
 - Sample collector's name, address, and telephone number;

- Laboratory's name, address, and telephone number;
- Description of sample;
- Quantity of sample; and
- Date of shipment.

The packaged samples will be delivered to the laboratory as soon as possible after sample acquisition.

A.4.7.4 Chain-of-Custody Control

After the samples have been collected, chain-of-custody procedures will be followed to establish a written record of sample handling and movement between the sampling site and the laboratory. Each shipping container will have a chain-of-custody form completed in triplicate by the sampling personnel. One copy of this form will be kept by the sampling contractor after sample delivery to the analytical laboratory, and the other two copies will be retained at the laboratory. One of the laboratory copies will become a part of the permanent record for the sample and will be returned with the sample analytical results. The chain-of-custody will contain the following information:

- Sample identification number;
- Sample collector's printed name and signature;
- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and
- Inclusive dates of possession.

The chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container, but will not be damaged or lost during transport. The shipping container will be sealed so that it will be obvious if the seal has been tampered with or broken.

A.4.7.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the ES field hydrogeologist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;

- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance,
 - Sample odor;
- Weather conditions;
- Water level prior to purging;
- Total well depth;
- Purge volume;
- Water level after purging;
- Well condition;
- Sampler's identification;
- Field measurements of pH, temperature, and specific conductivity; and
- Any other relevant information.

Ground water sampling information will be recorded on a ground water sampling form. Figure A.5 shows an example of the ground water sampling record.

A.4.8 Laboratory Analyses

Laboratory analyses will be performed on all ground water samples and the required QA/QC samples (see section A.4.9). The analytical methods and detection limit requirements for this sampling event are listed in Table 4.1 in the body of the TSTD/work plan.

Prior to sampling, arrangements will be made with the laboratory to provide a sufficient number of appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with laboratory protocol.

Laboratory personnel will specify any additional QC samples and prepare bottles for all samples. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory prior to shipping. Shipping containers, ice chests with adequate padding, and cooling media will be sent by the laboratory to the site. Sampling personnel will fill the sample containers and return the samples to the laboratories.

A.4.9 Quality Assurance/Quality Control Samples

Field QA/QC procedures for ground water will include collection of field duplicates and rinseate, field and trip blanks, decontamination of the water level probe, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., ground water), and analyses requested. Samples

will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of 4°C.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Ground water QA/QC sampling will include duplicates for up to three wells (i.e., frequency of 10 percent), rinseate blanks for up to three wells (i.e., frequency of 10 percent), one field blank, and a trip blank for each individual cooler sent to the analytical laboratory. The procedures for the collection of field QA/QC samples are described in Section A.7. The laboratory should plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested.

A.5 AQUIFER TESTING

Slug tests will be conducted at nine locations to estimate the hydraulic conductivity of the shallow saturated zone. Slug tests will be conducted at STW-01, STW-05, STW-14, STW-20, STW-23, STW-26, STW-29, ST14-01, and SD13-02. Pumping tests will not be conducted because large quantities of potentially contaminated water is generated and must be treated or disposed. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests are best used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test; in this field investigation both methods will be used in sequence.

A.5.1 Definitions

- **Hydraulic Conductivity (K).** A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.
- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible; a rising head or falling head test. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.
- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

A.5.2 Equipment

The following equipment is needed to conduct a slug test:

- Teflon[®], PVC, or metal slugs,
- One-quarter-inch nylon or polypropylene rope,
- Oil/water interface electric water level indicator,
- Pressure transducer/sensor,
- Field logbook/forms, and
- Automatic data recording instrument (such as the Hermit Environmental Data Logger, In-Situ, Inc. Model SE1000B or equal).

A.5.3 Test Methods, General

Aquifer hydraulic conductivity tests (slug tests) are accomplished by either removal of a slug or quantity of water (rising head) or introduction of a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Prior to testing, the monitoring well must be thoroughly developed as described in Section A.3.5 and water levels allowed to stabilize. Slug testing will proceed only after water level measurements show that static water level equilibrium has been achieved. During the slug test, the water level change should be influenced only by the introduction (or subtraction) of the slug volume. Other factors, such as inadequate well development, extended pumping, etc., may lead to inaccurate results. It is up to the ES field hydrogeologist to decide when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of the slug test, using the procedures described in Section A.4.3.

A.5.3.1 Falling Head Test

The falling head test is the first step in the two-step slug-testing procedure. The following steps describe the falling head test.

1. Decontaminate all down-hole equipment, following the decontamination procedures described in Section A.4.3, prior to initiating the test.
2. Open the well. Where wells are located within the 100-year flood plain, and equipped with water tight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the Aquifer Test Data form (Figure A.6) with entries for:
 - Borehole/Well number;
 - Project number;
 - Project name;
 - Aquifer testing team;

- Climatic data;
 - Ground surface elevation;
 - Top of well casing elevation;
 - Identification of measuring equipment being used;
 - Page number;
 - Static water level;
 - Date; and
 - Time intervals (0,1,3,5,7,9,10, and 12 minutes and every 3 minutes thereafter through 60 elapsed minutes, then in 10-minute intervals for the next hour, and in 30-minute intervals for the next 3 hours).
4. Measure the static water level in the well to the nearest 0.01 foot.
 5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by making periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
 6. Lower the decontaminated slug into the well to just above the water level in the well.
 7. Turn on the data logger, and quickly lower the slug below the water table being careful not to disturb the pressure transducer. Follow the owners' manual for proper operation of the data logger.
 8. Terminate data recording when the water level stabilizes in the well.

A.5.3.2 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the static water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the Owners Manual for proper operation of the Data Logger.
3. Terminate data recording when the water level stabilizes in the well. Remove the pressure transducer from the well and decontaminate.

A.5.3.3 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV and the method of Hvorslev (1951) for confined aquifers or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The standard slug test form (Figure A.7) is based on equations and test methods developed by Hvorslev (1951). Figure A.8 is the Bouwer and Rice Analysis Data Form. Figure A.9 contains the dimensionless parameters A, B, and C used for the Bouwer and Rice Analysis.

A.6 SURFACE WATER SAMPLING PROCEDURES

Surface water flow measurements will be collected from existing staff gaging locations to reconfirm surface water elevations and whether the stream is gaining or losing. The measurements will be made upstream of the oil/water separator outfall location at Farmers Branch, and downstream of this point near the Trinity River. To the extent practicable, existing continuous stream gaging information will be collected.

Samples will be collected so as not to cause cross-contamination. Background (i.e., upgradient) samples will be collected first. The surface water sample at each station will be collected so as to minimize the amount of suspended solids in the water sample. Surface water will be handled and transported in the same manner as ground water and soil samples. All samples will be placed in the appropriate containers with Teflon[®]-lined caps, and stored on ice in an insulated cooler.

Surface water samples will be collected by submerging unpreserved sample containers in the stream. Sample bottles that contained preservative will be filled by first filling an unpreserved sample bottle and transferring the sample into the preserved bottle. Surface water temperature, pH, and specific conductance will be measured at each sampling point.

Physical environmental information observed at each sampling site will also be recorded in the field notebook. This information will include the sample station location, the width, depth, and flow rate of the stream, surface water conditions such as floating oil, color, or debris, and the location of any nearby discharge pipes, sewers, or tributaries.

Surface water flow rates will be measured at three stations, once at the beginning of the field work and once again at its conclusion. Flow measurements will be taken at least one background sampling stations.

Field QA/QC procedures for surface water will include collection of a field duplicate, a field and trip blank, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., surface water), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of 4°C.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Surface water QA/QC sampling will include one duplicate, one field blank, and one trip blank (which can also be trip blank for ground water samples if surface water and ground water samples are placed in the same cooler sent to the analytical laboratory). The procedures for the collection of QA/QC samples are described in Section A.7. The laboratory should plan to conduct one laboratory control sample and one laboratory blank test for each specific analysis requested.

A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample

container while sampling activities are underway. A trip blank is designed to assess the effects of ambient conditions and transportation on sampling results. The trip blank will be placed within the cooler containing surface water samples prior to shipment.

A.7 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

As a check on field sampling, QA/QC samples, including trip blanks, field blanks, decontamination water blanks, equipment rinseate blanks, and field duplicates will be collected. Each type of QA/QC sample is described below.

A.7.1 Trip Blanks

A trip blank is defined as a sample bottle filled by the laboratory with analyte-free laboratory reagent-grade water, transported to the site, handled like a sample but not opened, and returned to the laboratory for analysis. One trip blank will accompany every cooler of environmental samples sent to the laboratory. Trip blanks are analyzed only for Method SW8020.

A.7.2 Decontamination Water Blank

A decontamination water blank is designed to check the purity of potable water used for equipment decontamination during the field operation. One decontamination water blank will be collected for each water source used during the field work. Decontamination water blanks are collected by filling the appropriate sample container directly from the potable water source. Decontamination water blanks are labeled, preserved, handled, and shipped in the same manner as an environmental water sample. The blank will be analyzed for the same analytes and parameters as the environmental samples.

A.7.3 Field Blanks

A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for the same analytes and parameters as the environmental samples.

A.7.4 Equipment Rinseate Blanks

Equipment rinseate blanks will be collected from field equipment such as continuous core barrels. Equipment rinseate blanks are prepared by pouring distilled water over field equipment that has been decontaminated. The rinseate water is then collected, transferred to a sample bottle, and analyzed at the laboratory. The results of these sample analyses indicate how well the sampling equipment was decontaminated.

A.7.5 Field Duplicate Samples

A field duplicate is defined as two or more samples collected independently at the same sampling location during a single act of sampling. Soil samples are divided into two equal parts for analysis. Duplicates of water samples will be collected by filling additional sample containers at each duplicated sampling event.

Field duplicates will be indistinguishable from other samples by the laboratory. One complete sample set will be identified with a coded identifier, which will be in the same format as other

identifiers used with this matrix. Both the coded and actual sample identifiers will be recorded in the field notebook. The coded identifier will be used on the chain-of-custody forms.

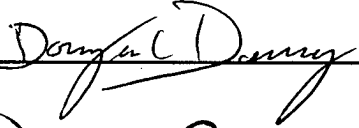
**ADDENDUM TO THE PROGRAM HEALTH AND SAFETY PLAN
FOR THE BIOVENTING TEST INITIATIVE**

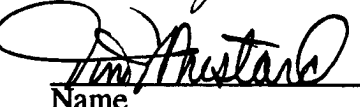
BASE NAME: CARSWELL AFB JOB #725520.02000

Site Manager: Brian Vanderglas

Site Contact: Frank Graves
(817) 731-8973

REVIEWED AND APPROVED BY:

Project Manager:  6/27/94
Name Date

Program H&S Manager:  6/27/94
Name Date

1.0 INTRODUCTION

This addendum modifies the existing *Program Health and Safety Plan for Risk-Based Remediation Demonstrations* (Engineering-Science, Inc., 1994), for conducting progressive site investigations at United States Air Force facilities under contract number F41624-93-C-8044.

This addendum to the health and safety plan was prepared to address the upcoming field tasks at Carswell AFB, Texas. The site to be investigated through a risk-based remediation approach will include Site ST14. Site 14 consists of two separate sites: ST14A, the Fuel Loading Area, and Site 14B, the petroleum, oil, and lubricant (POL) tank farm.

The demonstration to be conducted at Site ST14 of an innovative technology is being sponsored by the Air Force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas under Contract F41624-93-C-8004, "Risk-Based Approach to Fuel Spill Remediation."

Included or referenced in this addendum are site-specific descriptions, history and proposed bioventing pilot test activities; hazard evaluation of known or suspected chemicals; personal protective equipment (PPE); personnel decontamination procedures; site-specific training and medical monitoring requirements; air monitoring; site control procedures; employee exposure monitoring; and emergency response procedures.

2.0 SITE DESCRIPTION, HISTORY, AND SITE-SPECIFIC ACTIVITIES

The site description, history, and pilot test activities to be performed at this site are outlined in the site-specific work plan entitled *Work Plan for Engineering Evaluation/Cost Analysis In Support of Risk-Based Approach to Remediation at Site 14 at Carswell Air Force Base, Texas*. A brief listing of planned site-specific activities follows.

Services to be performed by ES at Site ST-14 include sampling of soil, soil gas, surface waters, and ground water.

A sufficient number of samples from background and contaminated areas will be collected and analyzed for individual and indicator compounds to accurately assess the risk to human health and the environment posed by the site and to demonstrate the attainment of final cleanup levels.

3.0 SITE-SPECIFIC EMPLOYEE TRAINING AND MEDICAL MONITORING REQUIREMENTS

See Section 4 of the program health and safety plan (Engineering-Science, Inc., 1994) for guidance.

4.0 HAZARD EVALUATION

4.1 Chemical Hazards

General hazards are addressed in the program health and safety plan. Site-specific hazards are identified below.

Chemicals known or suspected to occur at Site ST14 include petroleum hydrocarbon fuel components benzene, toluene, ethylbenzene, and xylenes (BTEX) as well as chlorobenzene.

Health hazard qualities for these compounds are presented in Table 5.1 of the program health and safety plan.

4.2 Physical Hazards

Potential physical hazards at this site include risks associated with the installation/operation of bioventing equipment such as underground utilities; overhead utilities; drilling activities; electrical equipment; heavy equipment; motor vehicles; slip, trip, and fall hazards; noise; and heat stress.

Protection standards for physical hazards are contained in Section 7 of the program health and safety plan.

5.0 AIR MONITORING

During operations that disturb site soils, a hydrocarbon detector or photoionization detector (PID or equivalent) will be used to measure ambient air concentrations in the worker breathing zone. As shown in the attachment, if the hydrocarbon detector measures total fuel vapor concentrations of 0-5 ppm, site workers will continue air monitoring in a Level D ensemble. If total fuel vapor concentrations reach 5-25 ppm for more than 30 seconds, and benzene concentrations exceed 1 ppm, site workers will evacuate the site or upgrade to Level B ensemble, if trained to do so. If benzene concentrations are less than 1 ppm, the site crews may continue in Level D ensemble with periodic air monitoring. If total fuel vapor concentrations reach 25-50 ppm for greater than 30 seconds and benzene concentrations exceed 1 ppm, site crews will evacuate the site or upgrade to Level B ensemble. If benzene concentrations are less than 1 ppm and vapors are in the range of 25-50 ppm, site workers will don full facepiece air-purifying respirators (APR) equipped with organic vapor cartridges (NIOSH approved), and continue periodic air monitoring. If total fuel vapor concentrations reach 50-500 ppm for greater than 30 seconds, the site crews will evacuate the site or upgrade to Level B ensemble. If total fuel vapor concentrations exceed 500 ppm for greater than 30 seconds, site crews will evacuate the site.

Before work can be performed in Level B respiratory protection the project manager must be notified. He will initiate the change order process with the Air Force or decide to halt activities at that site. (Level B operations require approval from corporate health and safety.) The site health and safety officer will determine whether it is safe to continue activities without respiratory protection or assign an upgrade to Level C protection. Flammable vapor monitoring will be conducted if potentially flammable atmospheres occur. See Sections 8 and 11 of the program health and safety plan for specific guidance.

6.0 SITE CONTROL PROCEDURES

Site control measures will be followed in order to minimize potential contamination of workers, protect the public from potential site hazards, and control access to the sites. Site control involves the physical arrangement and control of the operation zones

the methods for removing contaminants from workers and equipment. See Section 9 of the program health and safety plan for guidance.

Specific site control procedures at this site will include establishment of site work zones whenever employees are wearing respiratory protection. Unauthorized personnel will be restricted from entering the immediate work area.

7.0 PERSONAL PROTECTIVE EQUIPMENT

It is anticipated that Level D respiratory protection, with a contingency provision for the use of Level C will be used at these sites. Additional guidelines for the selection of respiratory protection at these sites are contingent upon the discovery of benzene vapors in the worker breathing zone while performing site activities. Site crews will assess the need for respiratory protection, or PPE, as applicable.

Protective clothing to be used at these sites includes:

- Hard hats
- Safety glasses
- Suits (Tyvek® or Saranex®)
- Respirator, if needed (APR with combination organic vapor/HEPA cartridges)
- Inner gloves (Latex or Vinyl)
- Outer gloves (Nitrile or Neoprene)
- Boots (Safety boots with latex boot covers)
- Other

8.0 PERSONNEL DECONTAMINATION PROCEDURES

See Section 10 of the program health and safety plan for general procedures and guidance. Of the compounds being used for decontamination, methanol is considered potentially hazardous. Methanol is volatile and flammable. The PEL for methanol is 200 ppm. An STEL of 250 ppm for 15 minutes is allowed for methanol. Exposure of the skin to methanol can result in skin burns and/or skin absorption.

The PEL for methanol can be reached when the PID is reading 8 ppm. This is because the relative response factor of methanol is 0.04 when the PID is equipped with a standard 10.2 or 10.6 eV lamp and is calibrated with 100 ppm isobutylene. Therefore, air monitoring should be performed when decontaminating equipment with methanol. If a respirator is needed during such operations, appropriate cartridges should be used. Nitrile gloves and chemical goggles should be used.

Methanol will be in plastic bottle jackets during use in the field. These bottle jackets will be properly labeled, and during transport into the field will be cushioned inside a larger locked-lid plastic carrying container that is secured in the vehicle. All chemical wastes (waste methanol) generated during decontamination will be collected in an empty manufacturer's chemical bottle with a bottle jacket, labelled with contents, dated, and transported as described above. Call the point-of-contact at the Air Force Base for proper disposal procedures and transport to the hazardous materials storage area.

9.0 EMPLOYEE EXPOSURE MONITORING

Employee exposure monitoring will be conducted on this site in accordance with Occupational Safety and Health Administration (OSHA) standards (29 CFR 1910) and the program health and safety plan.

10.0 EMERGENCY RESPONSE PLAN

10.1 Safe Distances and Places of Refuge

Prior to initiation of field activities, the field crew shall decide on safe distances to retreat to and select a place of refuge in the event of an emergency. This information shall be provided to all pilot test field personnel during weekly or daily site-specific safety briefings. All other guidelines established in the program health and safety plan for emergency planning, training, recognition, etc. shall be followed.

10.2 Emergency Information

Listed below are the name and phone numbers for medical and emergency services for this project.

Hospital	Harris Methodist Hospital
Address	1301 Pennsylvania Avenue Fort Worth, TX 76104
Phone	(817) 882-2000

Description of the route to the hospital:

From ST14, exist the main gate of the base and turn onto U.S. Highway 183 south. Exit to Interstate Highway 30 east. Take the Summit Avenue exit and head south (right). Turn east (left) on Pennsylvania Avenue. Signs near the hospital will aid in finding the appropriate entrance to the hospital.

Other Emergency Numbers:

Fire Department	911
Security Police	911
Ambulance	911
Crime	911

Program Health and Safety Manager:

Tim Mustard	work: (303) 831-8100
	home: (303) 450-9778

Project Manager:

Doug Downey	work: (303) 831-8100
	home: (303) 670-0512

11.0 REFERENCES

Engineering-Science, Inc. 1993. *Work Plan for Engineering Evaluation/Cost Analysis In Support of Risk-Based Approach to Remediation at Site ST14 at Carswell Air Force Base, Ft. Worth, Texas.*

Engineering-Science, Inc. 1992. *Program Health and Safety Plan for the Bioventing Test Initiative.* Denver, Colorado.

Hinchee, R.E., Ong, S.K., Miller, R.N., Downey, D.C., Frandt, R., 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing.* January.